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Model and Prototype Investigations

Civil Works Investigations 814 and 835

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U. S. Army Engineer Division, Ohio River
CORPS OF ENGINEERS
Cincinnati, Ohio

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ARMY-MRC VICKSBURG, MISS

PREFACE

A program of model studies of resistance of barge tows was authorized by the Chief of Engineers, U. S. Army, on 21 April 1948 as Civil Works Investigation 814, Resistance of Barge Tows. The program was later expanded to include a series of model tests which simulated prototype tests conducted under Civil Works Investigation 835, Prototype Tests of Resistance of Barge Tows. The added model tests were authorized by the Chief of Engineers on 16 November 1949. The Division Engineer, U. S. Army Engineer Division, Ohio River, was responsible for planning and coordinating the investigation.

The model studies were assigned to the District Engineer, U. S. Army Engineer District, Pittsburgh, Corps of Engineers, who contracted on 19 May 1948 to have the tests made by Professor Louis A. Baier, Chairman of the Department of Naval Architecture and Marine Engineering, University of Michigan. The tests were made in the naval tank of the University of Michigan at Ann Arbor, Michigan, during the period April 1949 to April 1954. The contract with Professor Baier included only the performance of scheduled tests, and furnishing the results in tabular form to the Pittsburgh District. The contract was terminated on 30 June 1954. Thereafter Professor Baier furnished to the Government, on a courtesy basis, substantial assistance in preparation of this report, particularly in connection with development of a method for analyzing the test results for restricted and shoal channels.

The tests were discussed with Professor Baier at Ann Arbor on several occasions by R. L. Irwin* and A. J. Moors of the Ohio River Division,

* Now with Board of Engineers for Rivers and Harbors.

T. B. Brett of the Pittsburgh District, and T. P. Bailey of the Louisville District. Representatives of other interested Districts and Divisions also visited the naval tank during the course of the tests. This report was prepared primarily by Mr. Moors.

CONTENTS

LIST OF SYMBOLS

A Cross-sectional area of channel in sq ft

B Width of tow in ft

C Ratio = $\frac{\text{TRHP - restricted or shoal channel}}{\text{TRHP - deep water}}$

D Depth of water in ft

g Acceleration due to gravity = 32.1616 ft/sec^2

H Draft of barge in ft

H_e Equivalent draft in ft = H (1 - 0.05N)

K Restricted channel parameter = $\frac{B \times H^2 \times 10^3}{M.W. \times D^2}$

K_d Constant, deep-water equation

L Length of tow at water line in ft

L_e Equivalent length of tow = $\frac{\nabla}{BH}$ in ft

M.W. Mean width of channel in ft = $\frac{A}{D}$

N Number of spaces between nonintegrated barges in tow

N_F Froude's number = $V/\sqrt{gL}$

N_R Reynolds number = VL/v

R Resistance in lb, subscripts T = total
F = frictional
p = prototype
m = model

S Wetted surface of tow in sq ft

T-M/hr Ton miles per hour (product of displacement of barge tow, in short tons, and its through-the-water speed, in mph)

TRHP Towrope horsepower

v Kinematic viscosity in ft^2/sec

V Speed of tow in mph

V_d Speed through deep water in mph

V_k Speed of tow in knots

$V_k/\sqrt{L}$ Speed-length ratio

V_x Speed at given depth in mph

Δ Displacement of tow in short tons

∇ Displacement of tow in cu ft

λ Linear scale ratio

ρ Mass density, slugs/ft^3 or lb-sec^2/ft^4

SUMMARY

The purpose of the study reported herein was to investigate channel effects on the resistance of barge tows.

Tests were conducted at 1:36-scale ratio in restricted, shoal, and nonrestricted straight channels. The restricted channels had prototype bottom widths of 125, 225, and 300 ft with 1-on-2 side slopes, while the shoal channels were 540 ft wide with vertical sides. Depths in the restricted and shoal channels varied from 6.5 to 30 ft. The channel dimensions for the nonrestricted-channel tests or "deep-water" tests were 792 ft wide and 342 ft deep, the limiting dimensions of the test tank cross section. A short series of tests was made in the same channels at a 1:15-scale ratio with the prototype dimensions varied to suit the larger scale. Seven different barges of varying sizes and shapes were tested in flotilla arrangements varying from single-barge to 8-barge tows. All barges in each flotilla were of the same size and loaded to the same draft, except for one series of tests with unequal drafts. Two series of the tests were for integrated and semi-integrated tows. Some of the tests simulated field tests and provided comparisons of model and prototype data.

Comparisons of model and prototype data indicate that speeds predicted from the model tests conform in general with those observed in field tests.

Relations were developed for shoal and restricted channels to indicate the relative effects of variation of channel dimensions on flotilla performance.

An equation was developed to evaluate flotilla performance in deep water. Results obtained from this formula compare reasonably well with results obtained from other model tests of larger tows.

RESISTANCE OF BARGE TOWS

Model and Prototype Investigations

PART I: INTRODUCTION

1. This investigation of channel effects on the resistance of barge tows was made to determine the transportation savings that will result from deeper and/or wider channels and the use of equipment adaptable to deeper drafts. It was initiated as a part of the 12-ft channel surveys for the Ohio and Mississippi Rivers conducted by the Ohio River Division, and the Great Lakes and Upper Mississippi River Divisions.* Originally, it was planned only to conduct performance tests on actual tows, and correlate the results with earlier model and prototype tests. This study was begun in August 1947 when the Dravo Corporation made a series of tests[5**] for the Pittsburgh District on reaches of the Ohio River between Pittsburgh, Pa., and Wheeling, W. Va. The tests were made on a 6-barge coal tow with towboat, furnished by Carnegie-Illinois Steel Corporation, to determine the quantitative effect of channel depth on the tow. In the meantime, the results of available model studies[9,10,12,13,21] had been reviewed but were found to cover ranges of draft and depth of water insufficient to serve the intended purpose. The study was expanded, therefore, to include both model and prototype tests and to obtain data for channels restricted in width as well as in depth. Model tests were begun in April 1949 at the naval tank of the University of Michigan, Ann Arbor, Mich. During July-August 1949, the Upper Mississippi Valley Division, assisted by Dravo Corporation, made field tests of resistance of an integrated and a semi-integrated tow on the Mississippi and Illinois Rivers.[6] The model testing program included tests to simulate the 1947 and 1949 prototype tests and tests made in 1936 on the Illinois and Mississippi Canal[21] to obtain a comparison between model results and the field tests. Reports on the field tests and other barge resistance studies related to the investigation presented in this report are listed in PART VII, REFERENCES.

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* Now North Central Division.

** Raised numbers refer to References at end of text.

PART II: MODEL TESTS

2. Testing Apparatus--The towing tank used in these tests is part of the equipment of the Department of Naval Architecture and Marine Engineering of the University of Michigan. It is 360 ft long by 22 ft wide and has a maximum depth of 9.5 ft. A diagrammatic sketch of the tank is shown in figure 1.

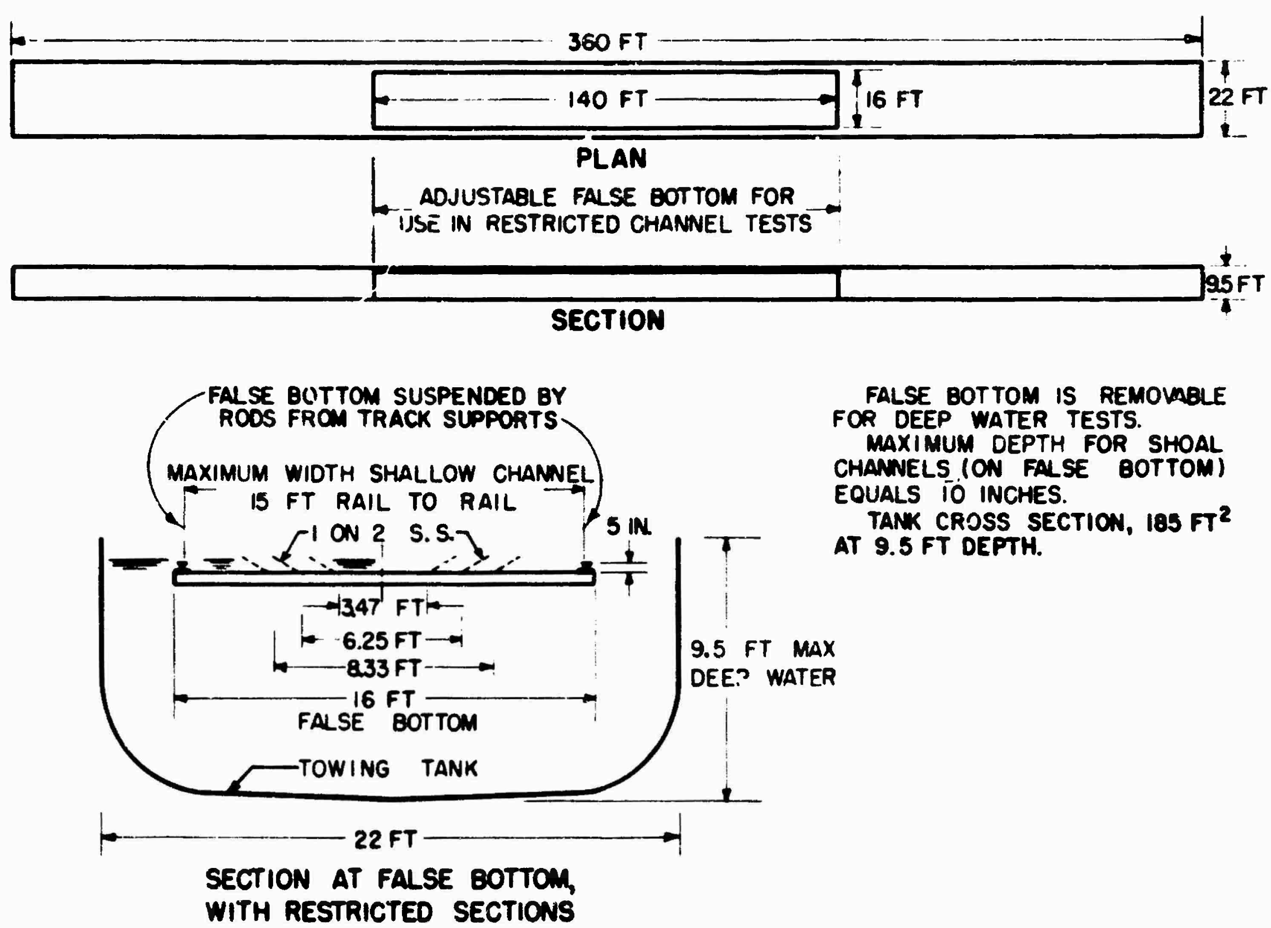


Figure 1. Elements of plan and section of towing tank

3. An adjustable false bottom, 140 ft in length, was used for shallow-water tests. The sides of the false bottom were paralleled by steel rails to keep the bottom from rising during tests. The rails were 15 ft apart, and about 5 in. high. For shoal-water tests in which the depth was not substantially greater than the height of the rails, the maximum available width of channel was about 15 ft. Channels restricted in depth and in width were constructed on the false bottom as indicated in figure 1. The false bottom extended through the middle part of the tank, leaving

approximately one-third of the tank at each end unrestricted in cross section.

4. Model tows were propelled by a towing carriage which contained a dynamometer mechanism to measure and record the tow resistance and speed. The carriage was mounted on wheels which were electrically driven along rails on each side of the tank. A water spray device on the carriage, in front of the towed model, was operated on the return trip to agitate the water and develop turbulence for the next test run.

5. The tank and testing apparatus are shown in figures 2-5.

6. Scale Ratios--Experience since 1906 with barge and flotilla model tests in the University of Michigan testing tank indicates that eddy-making is grossly exaggerated in small models, particularly at low speeds, and that the scale effect on fluid motion can be held to a minimum by using as large a linear scale ratio, λ , as is practicable with existing testing equipment. The capacity of the towing carriage limited the scale ratio for the larger tows to 1:36. This scale ratio was adopted for all the tests except those made for comparison with the Illinois and Mississippi Canal prototype tests. In the latter tests, a 1:15-scale ratio was used because the cross section of the Illinois and Mississippi Canal could be adapted directly from the larger 1:36-scale cross sections.

7. Model-Prototype Relations--The model barges were geometrically similar to the prototype barges. All surface relations varied as the square of the linear scale ratio, λ^2 , and volumes as λ^3 . In tests of this type both gravitational and viscous forces predominate. To satisfy both of these force requirements and obtain dynamic and kinematic similitude, the model was operated holding Froude's number, $V/\sqrt{gL}$, constant for the gravitational forces, while the viscous forces were estimated holding Reynolds number, VL/ν , constant. Less important forces, such as elastic and surface tension, were by necessity ignored. The resulting translation formula for predicting prototype performance was:

$$R_{T_p} = R_{F_p} + \left[\left(R_{T_m} - R_{F_m}\right)\frac{\rho_p\, g_p}{\rho_m\, g_m}\lambda^3\right] \tag{1}$$

Figure 2. Towing tank with false bottom and restricted channel in place

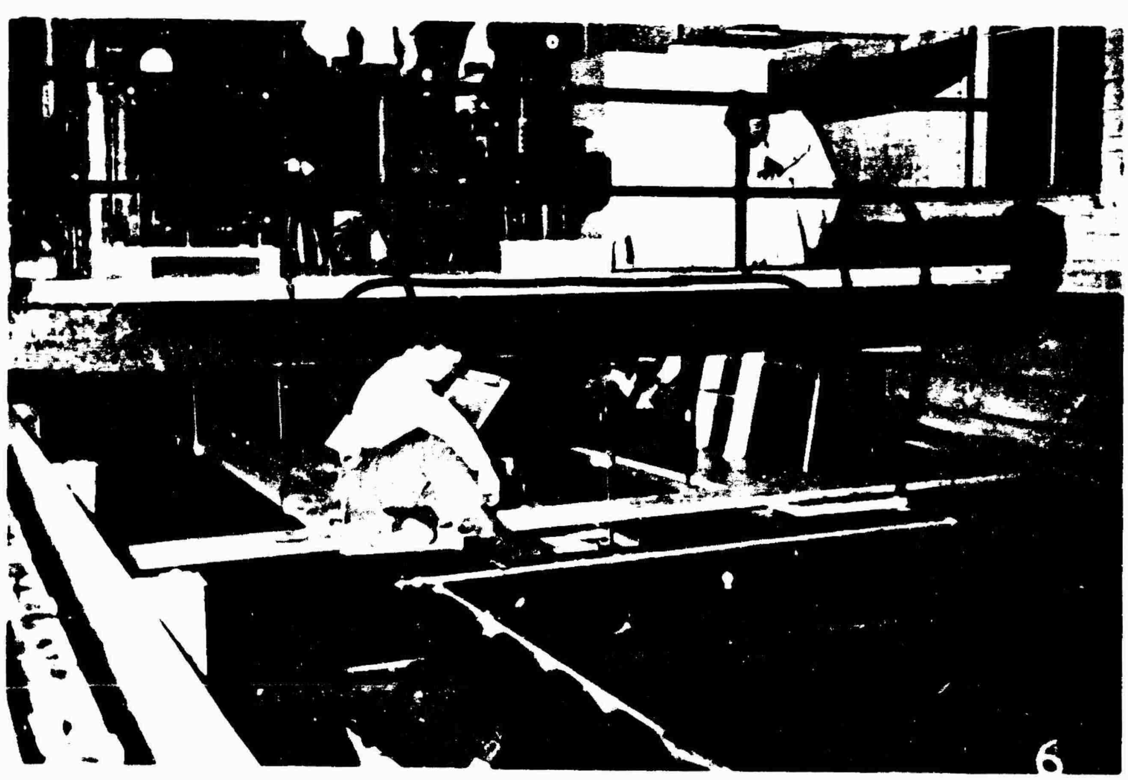


Figure 3. Dynamometer car propelling model barge

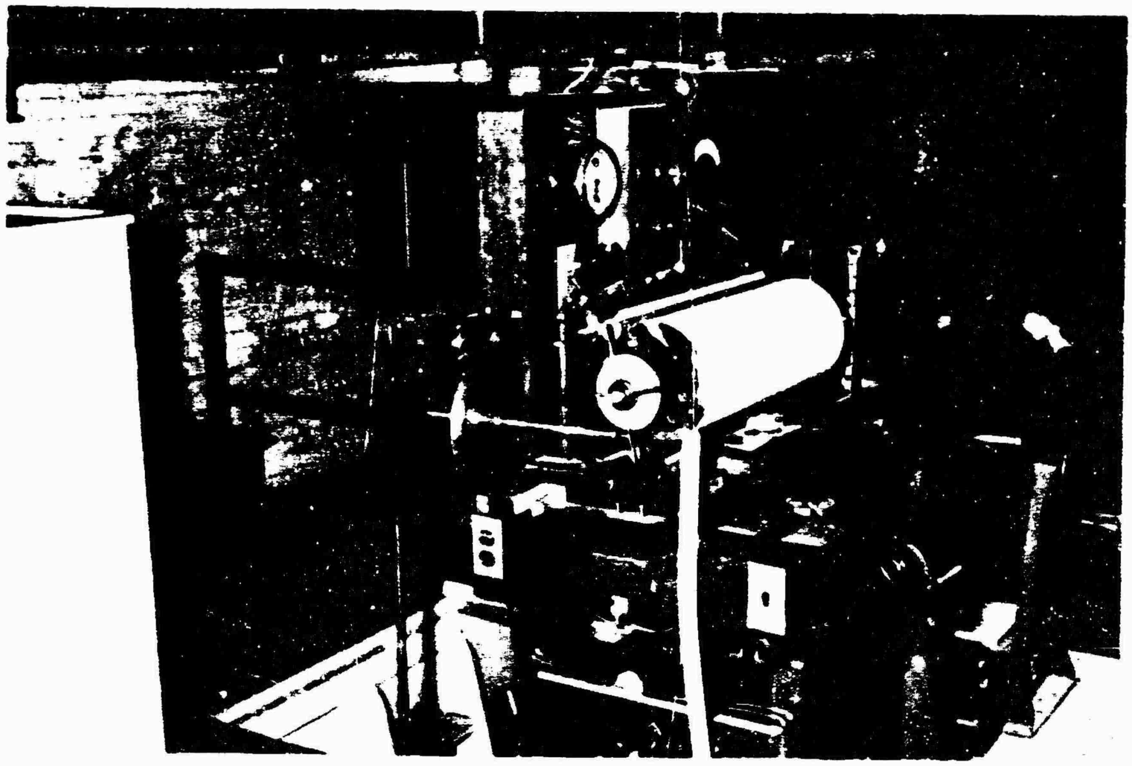


Figure 4. Dynamometer with recording drum

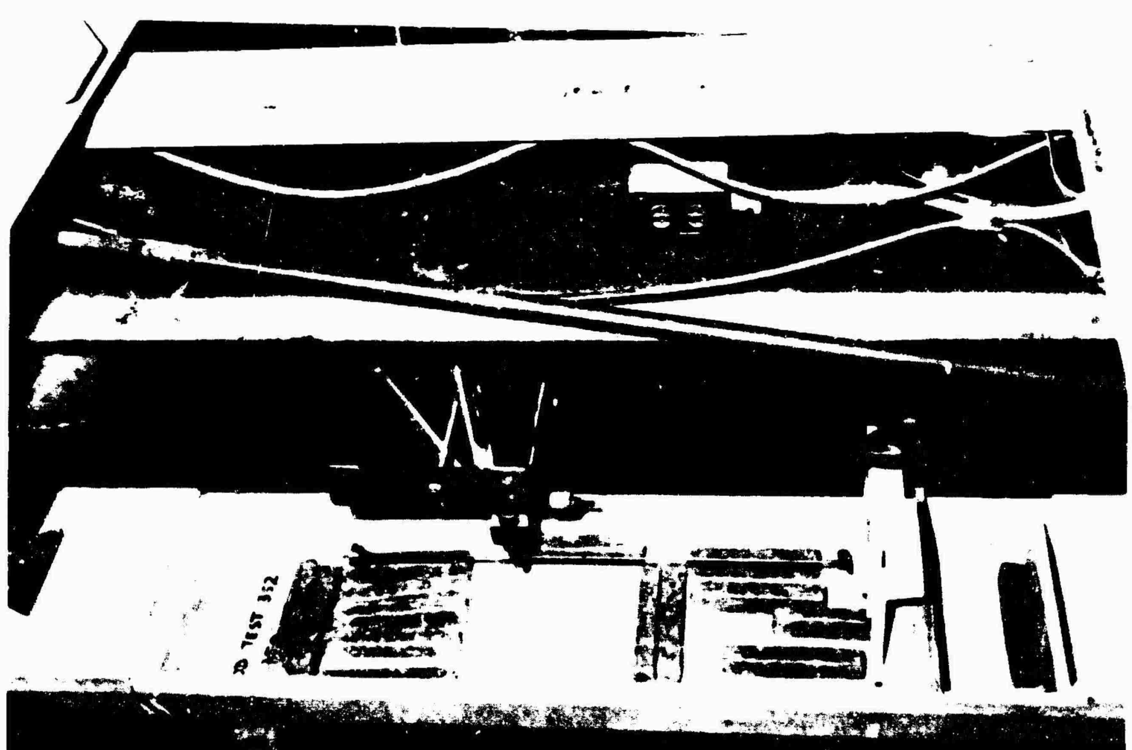


Figure 5. Model barge showing dynamometer connection, and bow at left with guide attachment

where

R_{T_p} = total resistance of the prototype in lb

R_{F_p} = estimated friction (viscous) resistance of the prototype in lb, including allowance for shell roughness

R_{T_m} = measured total resistance of the model in lb

R_{F_m} = estimated friction (viscous) resistance of the model in lb

8. Channel Sizes--Dimensions of prototype channels tested in the model are summarized in the following table.

	Scale Ratio	
	1:36	1:15
Restricted Channels		
Depths, ft	6.5 to 22	5.94 and 6.85
Bottom widths, ft	125, 225, 300	52.08, 93.75, and 125
Side slopes	1 on 2	1 on 2
Shoal Channels		
Depths, ft	9.5 to 30	6.85
Bottom width, ft	540	225
Side slopes	Vertical	Vertical
Deep-Water Channels		
Depths, ft	342	142
Widths, ft	792	330
Side slopes	Vertical	Vertical

9. Barge Models--Model barges were constructed of wood, and loaded to obtain the desired drafts. Each model was given a prime coat and finished with gray paint which was smoothed with steel wool to insure a consistent surface. A trip wire was installed at the PMB* on the lead barge of each tow to assure turbulent flow. The diameter of the trip wire varied with the size of the model. The increased resistance caused by the trip wire was offset by allowing laminar flow to occur ahead of it. Sketches of each type of barge listed on the following page precede the series of plates giving the results of the tests in which the barges were used.

* Parallel middle body.

Barge Dimensions Length, ft	Width, ft	Description	Shown on Plate No.
		Tests for General Data	
195	35	Standard barge	1
250	54	Jumbo barge*	14
195	35	Typical oil barge	28
		Tests for Comparison with Field Tests	
100	30	Used in 1936 tests on Illinois and Mississippi Canal	21
175	26	Coal barges used in 1947 tests on Ohio River	34
195	35	Integrated and semi-integrated gasoline barges used in 1949 tests on Mississippi and Illinois Rivers	38

* Tentatively proposed at the time tests were started.

10. Test Procedure--The comprehensive model test program was made up of test runs. Each test run consisted of movement of one tow formation or flotilla at one draft, at five to ten or more uniform speeds, through one depth of a restricted channel, or through deep water. In restricted-channel and shoal-channel tests the tow was brought to the desired speed in the deep-water approach to the false bottom. This speed was maintained as the tow passed through the false bottom section and into the far section of deep water. Prototype speeds generally ranged from 3 to 10 mph at the 1:36 scale, and 2 to 8 mph at the 1:15 scale. Resistance of the tow was recorded continuously by the dynamometer while the tow was at constant speed in the restricted channel and in the deep water beyond. Comparison of the deep-water resistance measurements afforded some control over the restricted-channel measurements in that departure from normal deep-water resistance served to indicate any deterioration of model surface or form. The consistency of the restricted-channel measurements was thereby improved.

11. Each flotilla was made up of similar barges and tested in accordance with usual practice and the limitations of the towing apparatus. Prior to the tests, resistance of a model barge, as measured in the tank of the University of Michigan, was compared with resistance measured for the same barge in the naval tank of the National Research Council at Ottawa, Canada. The agreement was excellent; the curves of resistance versus

velocity were virtually identical. The effect of adverse factors of viscosity and turbulence was minimized by the use of trip wires and other devices for creating turbulence. Also, the scale ratios of the tests were made as large as the testing apparatus would permit. The Reynolds number varied between 4.3×10^5 and 5.7×10^6.

12. Tests--The major part of the tests comprised a series of studies of resistance of tows in channels varying in width from 125 to 540 ft and in deep water. These tests were at the 1:36 scale. Four tows of standard barges 195 by 35 ft (plate 1) were used. These tows consisted of (a) two barges in tandem, (b) four barges 2 wide by 2 long, (c) six barges 2 wide by 3 long, and (d) six barges 3 wide by 2 long. Two tows consisted of a single, jumbo barge and two jumbo barges in tandem, each barge 250 by 54 ft (plate 14). Barges were arranged with the long rakes forward. The standard-barge tows were tested at drafts of 3, 5, and 8.5 ft. The tows of 250- by 54-ft barges were tested at drafts of 3, 8.5, and 14 ft. Each of the six tows was tested at each draft in four restricted channels at three depths each, and in deep water. Test depths for each tow are tabulated on the plates showing results.

13. Further restricted channel tests were made at the 1:15 scale for conditions approximating those of the field tests on the Illinois and Mississippi Canal.[21] Tows consisting of a single barge 100 by 30 ft (plate 21), or two such barges in tandem were tested. Single-barge drafts were 1.6, 2.8, and 4.5 ft. The 2-barge tow had drafts of 1.5, 2.8, and 4.4 ft. The bottom widths of restricted channels in which each tow was tested at each draft were 52.08, 93.75, and 125 ft. The side slopes were 1 on 2. Model test depths selected gave model channel areas virtually equal to prototype channel areas without departing significantly from the average prototype depth of 6.4 ft. The tows were also tested in a shoal channel 225 ft wide, and in deep water.

14. Four series of tests were made at the 1:36 scale with the false bottom providing shoal channels with the maximum practicable width of 540 ft. Test depths are as shown in the plates giving results. Deep-water tests were also made. These series of tests are described in the following subparagraphs.

a. A tow of eight oil barges (195 by 35 ft; see plate 28) arranged in a flotilla 2 wide by 4 long, to simulate a standard Mississippi River tow of this type of barge, was tested at drafts of 5, 7, 8.5, 9.5, and 10.5 ft. For drafts of 9.5 and 10.5 ft, which are greater than the normal draft of 8.5 ft, it was necessary to extend each model barge as shown on plate 28.

b. A tow simulating six coal barges (175 by 26 ft as shown on plate 34) 3 wide by 2 long was tested at drafts of 5, 8.5, and 10 ft to simulate the 1947 field tests.[5]

c. Model tests of two tows of oil barges (195 by 35 ft) were made for a 4-barge, 2 wide by 2 long, integrated tow and an 8-barge, 2 wide by 4 long, semi-integrated tow to simulate the 1949 field tests.[6] These barges and tows are shown on plate 38. The 4-barge tow was tested at a 7.3-ft draft in five depths including deep water. The 8-barge tow was tested at a 7.5-ft draft at five depths including deep water.

15. Incidental tests at a scale of 1:36 were made in addition to the formal schedule of tests for restricted channels to investigate effect of variable draft and of rake positions. Test conditions are defined on plates 52, 53, and 54. Reference to these tests, and the results are included for general information.

16. Results--Model test results were converted to prototype values by Professor Baier using the procedure described in paragraph 7. Frictional resistance was computed from Schoenherr's coefficients for smooth surface and corrected to account for the extra resistance of a normal steel hull over a smooth basic surface. In the restricted-channel tests, correction was made for backflow velocity.

17. The data developed from these tests are presented in graphic form, together with the barge designs tested, on plates 1 through 40. The graphs show curves for prototype resistance in towrope horsepower versus prototype speeds in miles per hour. The curves, for the channel conditions indicated on the plates, were drawn through points computed from model test data.

18. In general, consistent results were obtained from the test data. Insufficient turbulence of the water in the tank and other factors, however, made it difficult to obtain consistent results at the lower speeds. In

plotting these portions of the curves, considerable reliance was placed on data obtained at higher speeds. Test results show an irregular trend over the speed range when the depth of water was shallow compared to the draft of the tow, particularly when the width of the channel also was restricted. The tendency for the model flotilla to squat and hit bottom in shallow depths resulted in some runs being limited to maximum speeds of about 4.5 mph. Similar behavior and limitations of speed occur when prototype flotillas are operating in channels where the depth is shallow compared to the draft of the tow. This irregular trend is the result of the following actions, all of which are a function of the speed of the tow: (a) the actual level of the channel water decreases during the passage of the tow; (b) the model changes trim due to change in relative position of wave crests and troughs; (c) the tow squats (sinks bodily) due to changes in relative pressures between bottom of tow and channel bottom; and (d) the relative influence of the wave of translation affects the resistance of the tow.

PART III: PROTOTYPE TESTS

19. Tests--Three sets of data developed from full-scale prototype tests were utilized for comparison with towrope horsepowers developed from the model tests. These prototype tests are described briefly in the following paragraphs:

a. Illinois and Mississippi Canal.[21] The Rock Island District, Corps of Engineers, conducted a series of prototype tests in three different reaches of the Illinois and Mississippi Canal in 1936. In these tests, tows of one and two 100- by 30-ft barges were pushed by a launch through test reaches of the canal, selected for uniform cross section and alignments. Tests were made for three different drafts. Resistances, attributable to the movement of the barges through the canal, are plotted as observed towrope horsepowers versus speeds on plates 41 through 46.

b. Ohio River.[5] The Dravo Corporation and the Pittsburgh District, Corps of Engineers, conducted prototype tests with a loaded coal tow in straight sections of the Ohio River between Pittsburgh, Pa., and Wheeling, W. Va., in August 1947. The tow consisted of six standard coal barges, 175 by 26 ft, arranged three abreast by two long and loaded to a draft of 8.5 ft. Total displacement of the six coal barges was 6588 short tons. The tow was pushed through the test reaches under the full power of a stern-wheel towboat. Resistances were measured by a Dravo dynamometer barge which was placed between the towboat and the coal barges. Prototype data plotted on plates 47, 48, and 49 are based on measurements in channels with depths of 11.5 ft or greater.

c. Mississippi and Illinois Rivers.[6] The Dravo Corporation and the Upper Mississippi Valley Division, Corps of Engineers, conducted prototype tests on a 4-barge and on an 8-barge fleet of oil barges on the Mississippi and Illinois Rivers in August 1949. The 8-barge formation consisted of a 6-barge integrated unit of 195- by 35-ft barges, 2 wide by 3 long, and 2 standard barges of the same over-all dimensions in tandem. The 4-barge formation consisted of the fore and aft sections of the integrated tow. The tows were pushed through the test reach by a twin-screw diesel towboat. Dimensions of the tow and arrangements of the units are

shown on plate 38. The prototype curves, shown on plates 50 and 51, are based on measurements in channels with depths in excess of 11 ft.

20. Results--The data obtained in the prototype tests conducted on the Ohio, Mississippi, and Illinois Rivers provide a basis for comparison with the model results in channel depths in excess of about 11-1/2 ft. At lesser depths the resistances encountered were very sensitive to minor changes in channel depths, which were neither uniform throughout the test reaches nor necessarily correctly represented by the average of depth readings recorded on a single line of soundings under the tow. These factors have a lesser effect on the results of tests made in deeper water. Other irregularities in prototype test results are attributed to the effects of currents, passing tows, use of rudders, and acceleration or deceleration of the prototype barges in the test reaches. The latter effect was particularly noticeable when the prototype tow had built up an excessive entrance speed in deep water prior to entering a shallow test reach. Channel widths were sufficiently large in each instance to have a negligible effect on the test results.

PART IV: COMPARISONS OF MODEL AND PROTOTYPE TEST RESULTS

21. Inspection of plates 41 through 51 indicates that speeds obtained from the model tests conform in general with speeds observed in the field tests. Specific comparisons are shown in tables 1 and 2. These comparisons indicate closer agreement between model and prototype speeds for the larger channels. The data in the tables indicate that the model tends to underestimate the beneficial effects derived from channel enlargements. The validity of any direct comparisons is questionable, however, because of the lack of similarity between model and prototype and the inherent errors in prototype testing. In making comparisons the following should be considered: <u>first,</u> the model tests described in this report were made without towboats and dynamometer barges and do not reflect the interaction of resistance between tow and towboat and the effect of increased water-line length on wave-making forces; <u>second,</u> scale effect, which was not investigated in these tests, affects the comparisons; <u>third,</u> comparable speed must be determined through the water and not over the ground as was done in the tank (correction for currents must be obtained); <u>fourth,</u> the cross-section contour of the actual river is never the same as the cross section of the tank; <u>fifth,</u> as power increases on towboat there is a tendency for water to be sucked out from under the tow which then results in increased draft and lower speed; and <u>sixth,</u> tows in a river with current are following the gradient of the water slope and hence have an increased speed downstream and a decreased speed upstream.

Table 1

Model-Prototype Speed Comparisons

Channels Restricted in Depth and Width

Model Scale 1:15

Mississippi and Illinois Canal

Channel Area, sq ft	Depth, ft	Bottom Width, ft
450	6.85	52.08
620	5.94	93.75
811	5.94	125.00

Plate No.	Draft ft	Channel Area sq ft	Speed, mph Model	Speed, mph Prototype	Prototype Speed % of Model Speed
One, 100- by 30-ft Barge; 20 TRHP					
41	1.6	450	5.18	4.78	92
		620	5.33	5.18	97
		811	5.50	5.50	100
42	2.8	450	4.10	3.67	90
		620	4.29	4.05	95
		811	4.60	4.43	96
43	4.5	450	2.98	2.55	86
		620	3.20	2.98	93
		811	3.38	3.20	95
Two, 100- by 30-ft Barges; 20 TRHP					
44	1.5	450	4.58	4.32	94
		620	4.70	4.65	99
		811	4.79	4.85	101
45	2.8	450	3.60	3.18	88
		620	3.77	3.55	94
		811	4.04	3.77	93
46	4.4	450	2.70	2.30	85
		620	2.90	2.65	91
		811	3.18	2.88	91

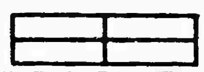
Table 2

Model-Prototype Speed Comparisons

Channels Restricted in Depth (Only)

Model Scale 1:36

Ohio, Mississippi, and Illinois Rivers

Plate No.	Draft ft	Channel Depth ft	Speed, mph Model	Speed, mph Prototype	Prototype Speed % of Model Speed
Six, 175- by 26-ft Barges  ; 240 TRHP					
47	8.5	10	4.78	4.14	86
		11	4.87	4.51	93
		13	5.00	4.81	96
		15	5.12	4.97	97
		20	5.37	5.17	96
		30	5.72	5.40	94
Four, 195- by 35-ft (Integrated) Barges  ; 350 TRHP					
50	7.3	11.5	6.00	6.25	104
		14	6.35	6.78	107
		18	6.80	7.40	109
		28	7.30	7.97	109
Eight, 195- by 35-ft (Semi-Integrated) Barges  ; 500 TRHP					
51	7.5	11.5	6.44	5.87	91
		14.0	6.55	6.22	95
		18.0	6.77	6.68	99
		28.0	7.02	7.25	103

PART V: ANALYSIS

22. The analysis has been limited to determination of the effect of channel dimensions on flotilla performance and the applicability of the resulting relations to larger flotillas. All of the test results are presented on plates 1 through 40 to form a permanent record of the model tests and provide a ready reference for further analysis.*

23. Flotilla Performance--The unit "ton-miles per hour" was selected to provide a single quantity for evaluating the effects on flotilla performance of changes in the size, draft, and horsepower of tows, and of changes in performance which would result from channel enlargements. The unit of ton-miles per hour, ($T\text{-}M/_{hr}$), is the product of the displacement of the barge tow, in short tons, and its through-the-water speed in miles per hour.

a. Deep-Water Channels. Ton-mile per hour performance of barge tows in nonrestricted, "deep-water" channels varies for any given towboat depending on the number, size, draft, and formation of its barge fleet, and for any given fleet of barges depending upon the push horsepower applied by the towboat. These performance variations were studied separately in deep-water channels to provide a basis for evaluating the effects of channel restrictions on the performance of like tows in shoal- and restricted-channel sections. The following empirical formula was developed:**

$$T\text{-}M/_{hr} = K_d(H_e)^{0.87}\,(B)^{0.65}\,(TRHP)^{0.35} \qquad (2)$$

where

$T\text{-}M/_{hr}$ = ton-miles per hour
K_d = constant, obtained from figure 6
H_e = equivalent draft in ft = $H(1 - 0.05N)$
H = draft in ft

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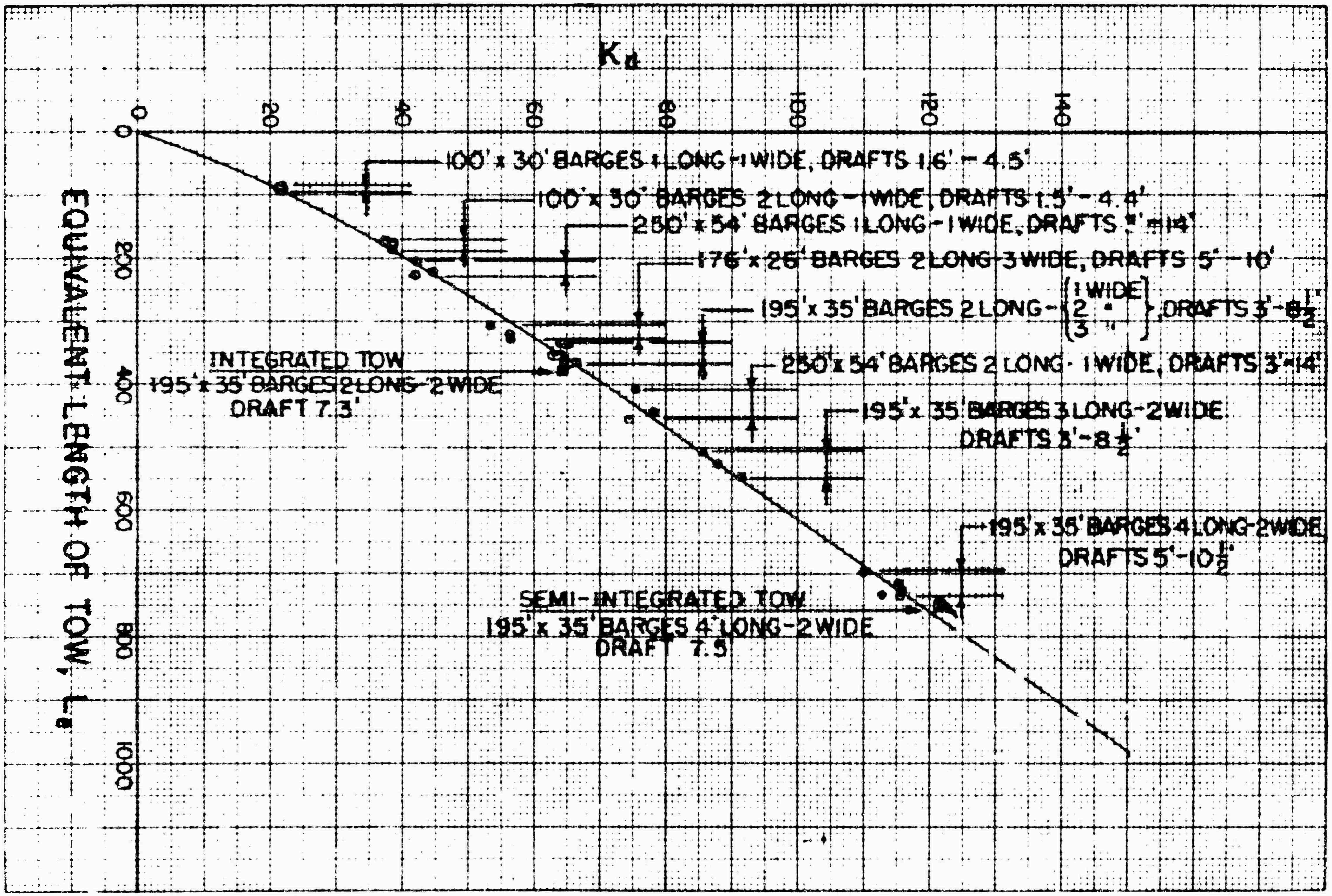
* Data sheets for each model test run are on file in the U. S. Army Engineer Division, Ohio River, CE, Cincinnati, Ohio, and the U. S. Army Engineer District, Pittsburgh, CE, Pittsburgh, Pa. Copies of the data sheets are available from the latter office.

** From an analysis made by T. P. Bailey, U. S. Army Engineer District, Louisville, CE, Louisville, Ky.



K_d
0
20
40
60
80
100
120
140
EQUIVALENT LENGTH OF TOW, L_e
200
400
600
800
1000
100' x 30' BARGES 1 LONG-1 WIDE, DRAFTS 1.6' - 4.5'
100' x 30' BARGES 2 LONG - 1 WIDE, DRAFTS 1.5' - 4.4'
250' x 54' BARGES 1 LONG - 1 WIDE, DRAFTS
176' x 26' BARGES 2 LONG-3 WIDE, DRAFTS 5' - 10'
195' x 35' BARGES 2 LONG - {1 WIDE, 2 ", 3 "}, DRAFTS 3'-8½'
250' x 54' BARGES 2 LONG - 1 WIDE, DRAFTS 3'-14'
195' x 35' BARGES 3 LONG-2 WIDE
DRAFTS 3'-8½'
195' x 35' BARGES 4 LONG-2 WIDE
DRAFTS 5'-10½'
INTEGRATED TOW
195' x 35' BARGES 2 LONG-2 WIDE
DRAFT 7.3'
SEMI-INTEGRATED TOW
195' x 35' BARGES 4 LONG-2 WIDE
DRAFT 7.5'

N = number of spaces between nonintegrated barges in tow

B = width of tow in ft

TRHP = towrope horsepower

The plotted points shown in figure 6 are the average values of K_d for the speed range of the individual tests. Relating K_d to L_e partly corrects for the effect of the length of the tow on frictional resistance and the rake effect for different-shape barges. The range of data used in the computations is as follows:

T-M/hr	390 to 134,880
Length of tow, L_e	87.0 to 749.1 ft
Draft, H	3 to 14 ft
Width, B	30 to 105 ft
TRHP	2 to 1000

b. Shoal Channels. The performance of a tow in shallow water can be expressed as a percentage of the performance in deep water.[20] For any given flotilla this is the ratio of its speed through shallow water to its speed through deep water. Analysis of the shoal-water test results for the larger flotillas shown on plates 10, 13, 31, and 36 has indicated that the ratio of the speed at a lesser depth to the speed in deep water can be expressed by the formula:*

$$\frac{V_x}{V_d} = \tanh \left(0.0111 \frac{L}{B} + 0.235\right) (D - H + 10)^{0.523} \tag{3}$$

where

V_x = speed at depth D in mph

V_d = speed through deep water in mph

L = length of tow at water line in ft

B = width of tow in ft

D = depth of channel in ft

H = draft in ft

Although this formula was developed from test data for a draft of 8.5 ft it can be used for drafts between 5 and 10.5 ft with small error.

---

* Developed by personnel in U. S. Army Engineer Division, Ohio River, CE, Cincinnati, Ohio.

(Spot checks indicate less than 5 per cent error.) Since the speed ratio is the same as the $T\text{-}M/_{hr}$ ratio for any given flotilla, formulas (2) and (3) can be combined to give a general expression for flotilla performance in shoal channels.

c. Shoal and Restricted Channels (Professor Baier's Analysis). The test results for each flotilla were analyzed individually rather than combined as in the foregoing analysis. Channel dimensions and barge draft were related by the parameter $K = \frac{B \times H^2 \times 10^3}{M.W. \times D^2}$ for the restricted-channel tests, and the parameter H/D for the shoal-channel tests. Relations were developed for each flotilla between these parameters and the TRHP ratio, C , for various speed-length ratios, $V_k/\sqrt{L}$. Plots of these relations are shown on plates 55 through 101. Preceding these curves for each flotilla are curves to convert $V_k/\sqrt{L}$ to mph and $T\text{-}M/_{hr}$. The plots also permit converting miles per hour to ton miles per hour. L in this analysis is the water-line length.

24. Conversion Formulas. Resistance data are sometimes given in pounds, R_T , or in pounds per short ton of displacement, R_T/Δ . The following formulas are included for convenience in comparing data in this report with other published data.

$$R_T = \frac{375\ TRHP}{V(mph)} \qquad (4)$$

$$\frac{R_T}{\Delta} = \frac{TRHP}{.0030707\ \Delta V_k} \qquad (5)$$

25. Applicability to Larger Flotillas--Data published by Horton[8] for a 12-barge tow, 3 wide by 4 long, which was tested at the Netherlands Ship Model Basin at Wageningen, Netherlands, have been compared with results obtained by formula (2). The tow was composed of Dravo A-13 barges, shown on plate 1, and was tested for deep-water conditions at a 1:36 scale without towboat. Comparative resistances are as follows:

Speed mph	Resistance in lb	
	Netherlands Tests	Formula (2)
5	26,000	25,000
6	35,500	35,000
7	47,500	46,800
8	61,000	60,100
9	76,500	74,800

The agreement shown in this comparison indicates that formula (2) is applicable to larger tows than tested for this report. For economic studies of navigation facilities, where relative values of increase in speed are desired, formulas (2) and (3) will give the desired accuracy.

PART VI: CONCLUSIONS

26. Speeds obtained from the model tests conform in general with speeds observed in the field tests. The dissimilarity between model and prototype flotilla tests precludes precise comparisons.

27. The generalized relations developed for shoal and restricted channels provide a means for determining the relative increase in efficiency of flotilla performance obtained from channel enlargement.

28. The equation developed for flotilla performance in deep water is applicable with reasonable accuracy to prototype tows larger than those tested in the model.

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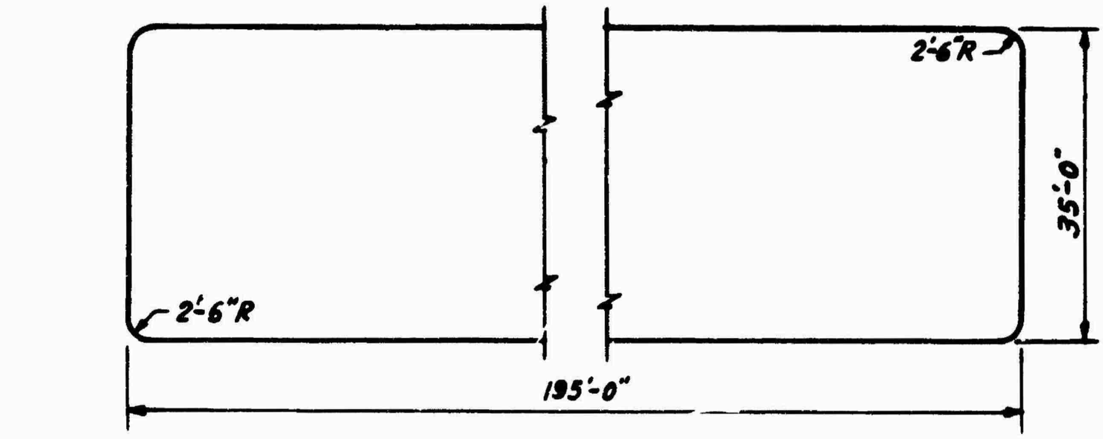
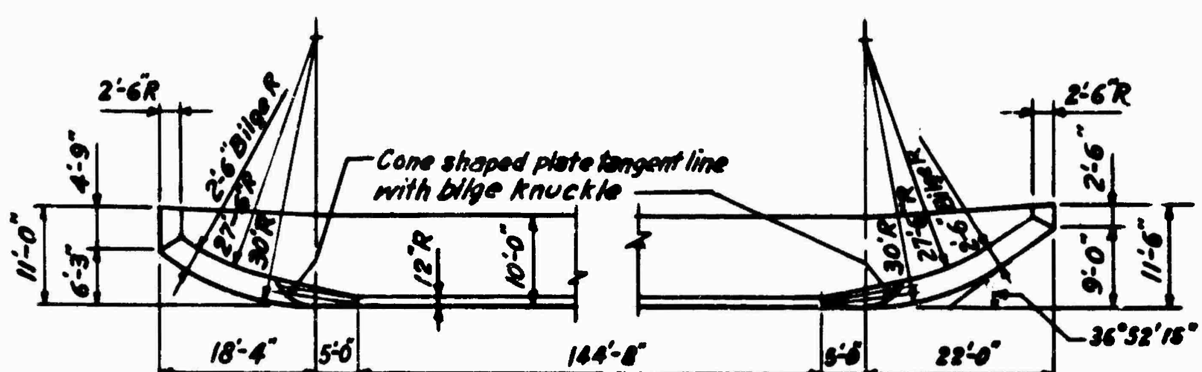


PLAN



ELEVATION

NOTE:
Barge design follows
Dravo CORP Barge Model A 13

195-FT X 35-FT BARGE
FOR TESTS ON
PLATES 2 TO 13 INCL.

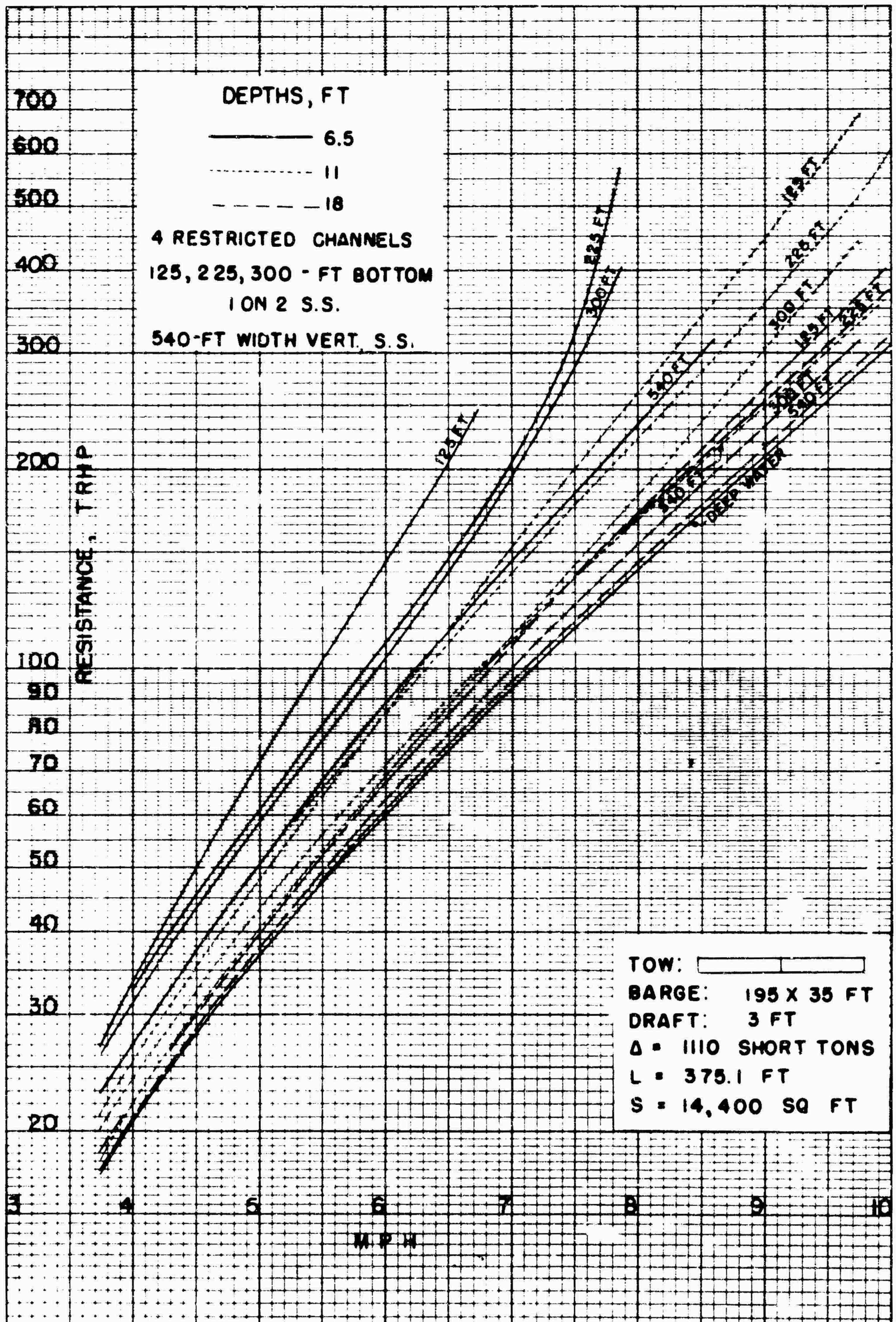
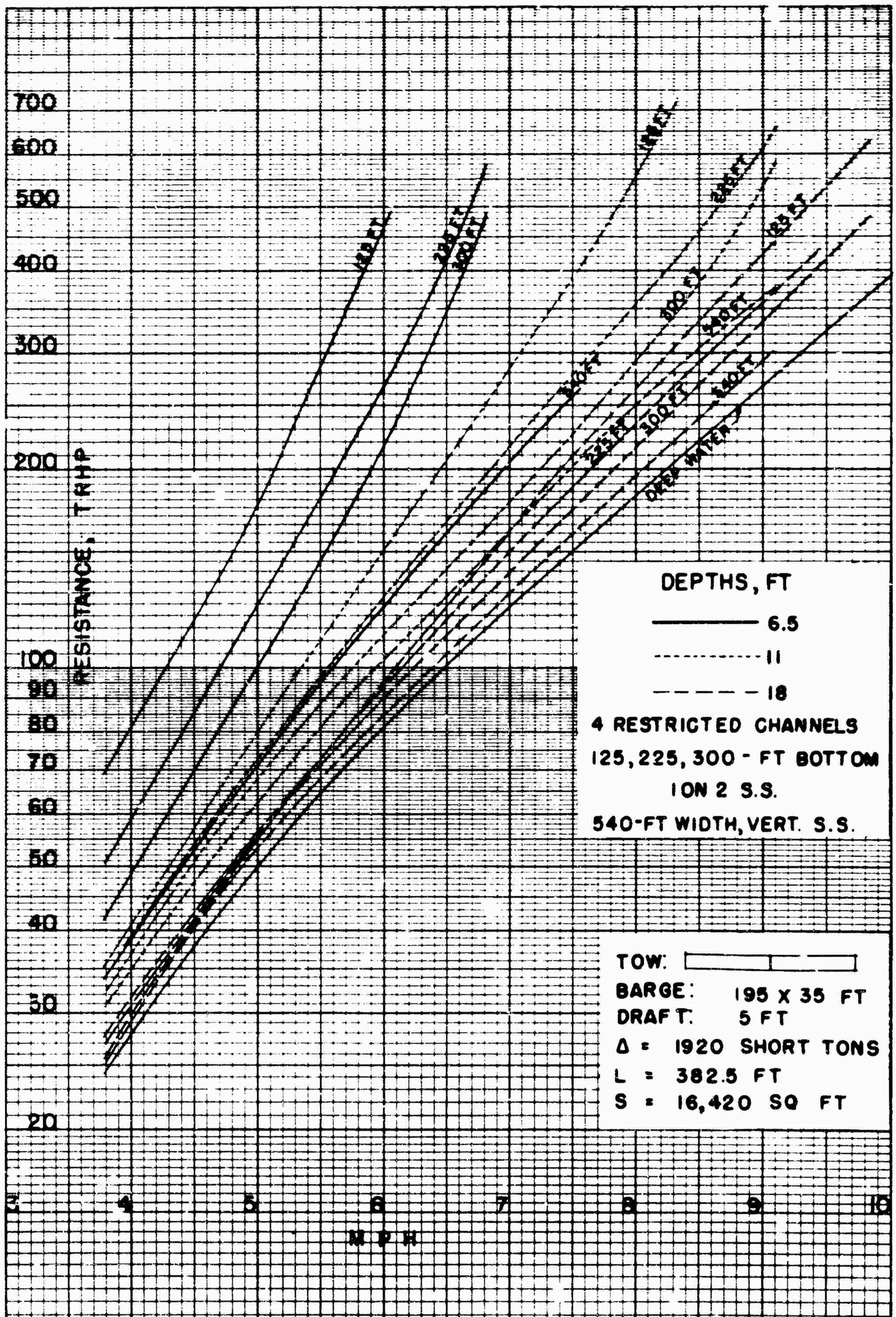
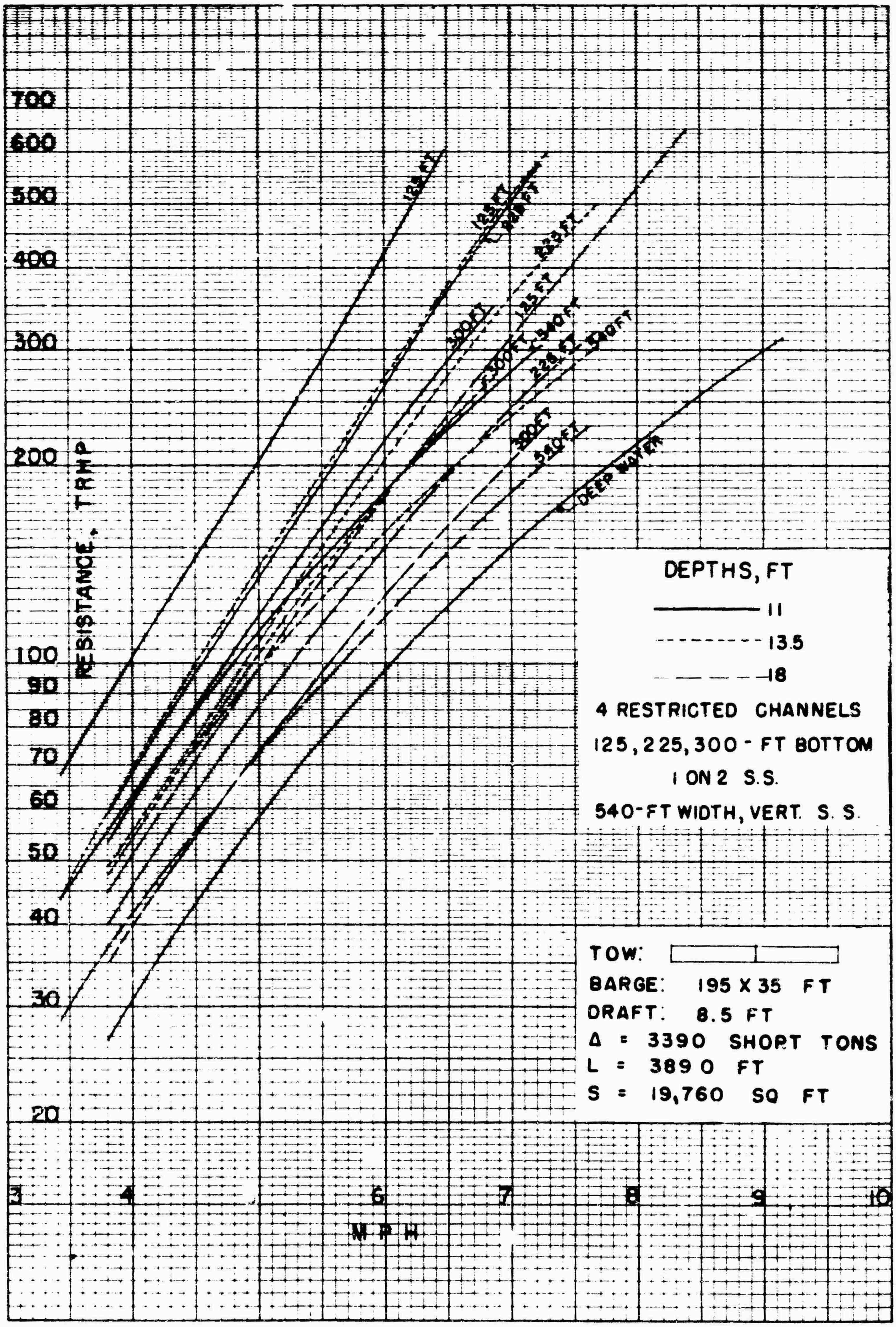

DEPTHS, FT
6.5
11
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH VERT. S.S.
TOW:
BARGE: 195 X 35 FT
DRAFT: 3 FT
Δ = 1110 SHORT TONS
L = 375.1 FT
S = 14,400 SQ FT
RESISTANCE, TRHP
MPH
125 FT
225 FT
300 FT
540 FT
DEEP WATER

PLATE 2



RESISTANCE, TRHP
M P H
DEPTHS, FT
6.5
11
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S.S.
TOW:
BARGE: 195 X 35 FT
DRAFT: 5 FT
Δ = 1920 SHORT TONS
L = 382.5 FT
S = 16,420 SQ FT
DEEP WATER



RESISTANCE, TRHP
M P H
DEPTHS, FT
11
13.5
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S. S.
TOW:
BARGE: 195 X 35 FT
DRAFT: 8.5 FT
Δ = 3390 SHORT TONS
L = 389 0 FT
S = 19,760 SQ FT
DEEP WATER

PLATE 4

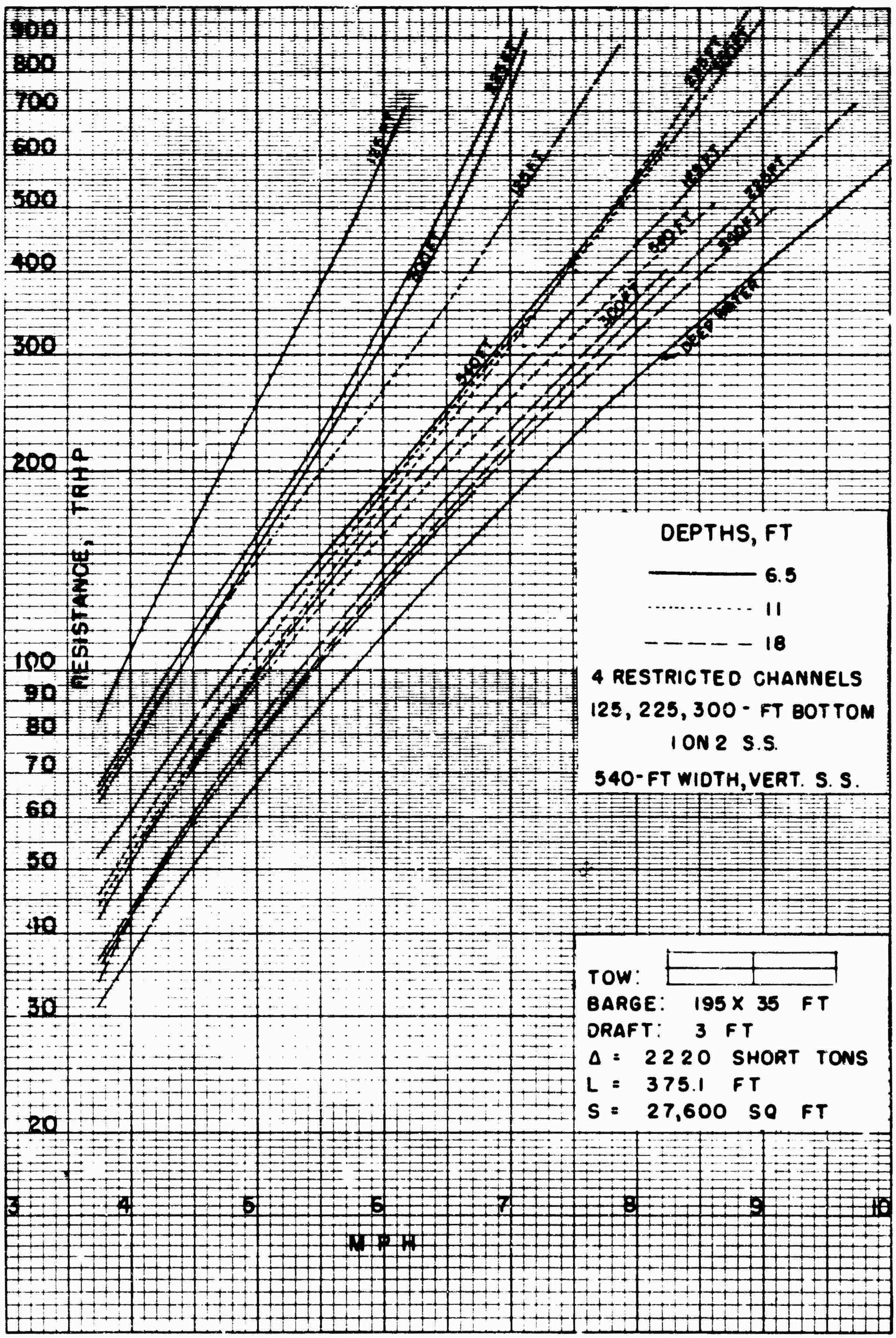

RESISTANCE, TRHP
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
3
4
5
6
7
8
9
10
M P H
DEEP WATER
DEPTHS, FT
6.5
11
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S. S.
TOW:
BARGE: 195 X 35 FT
DRAFT: 3 FT
Δ = 2220 SHORT TONS
L = 375.1 FT
S = 27,600 SQ FT

PLATE 5

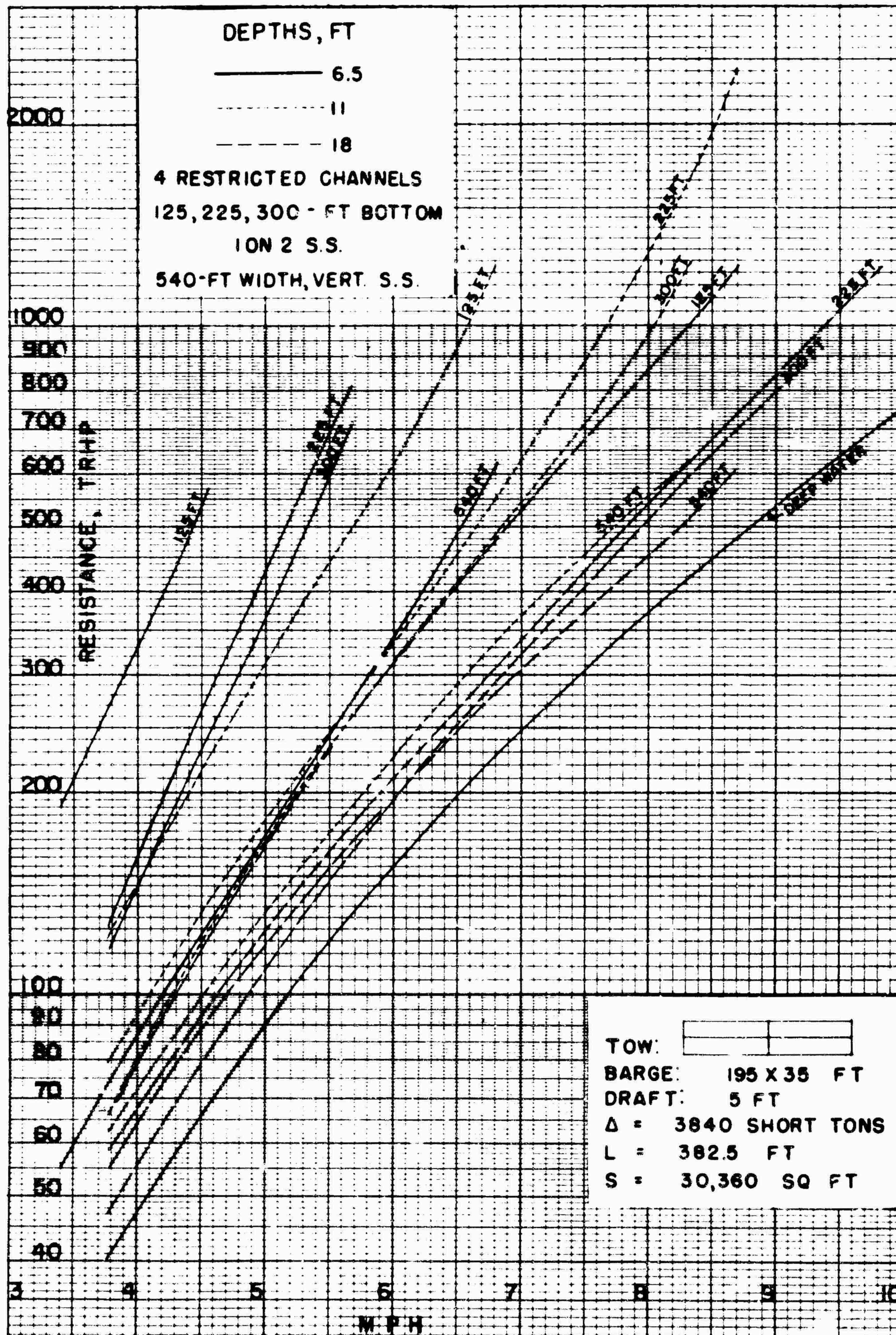
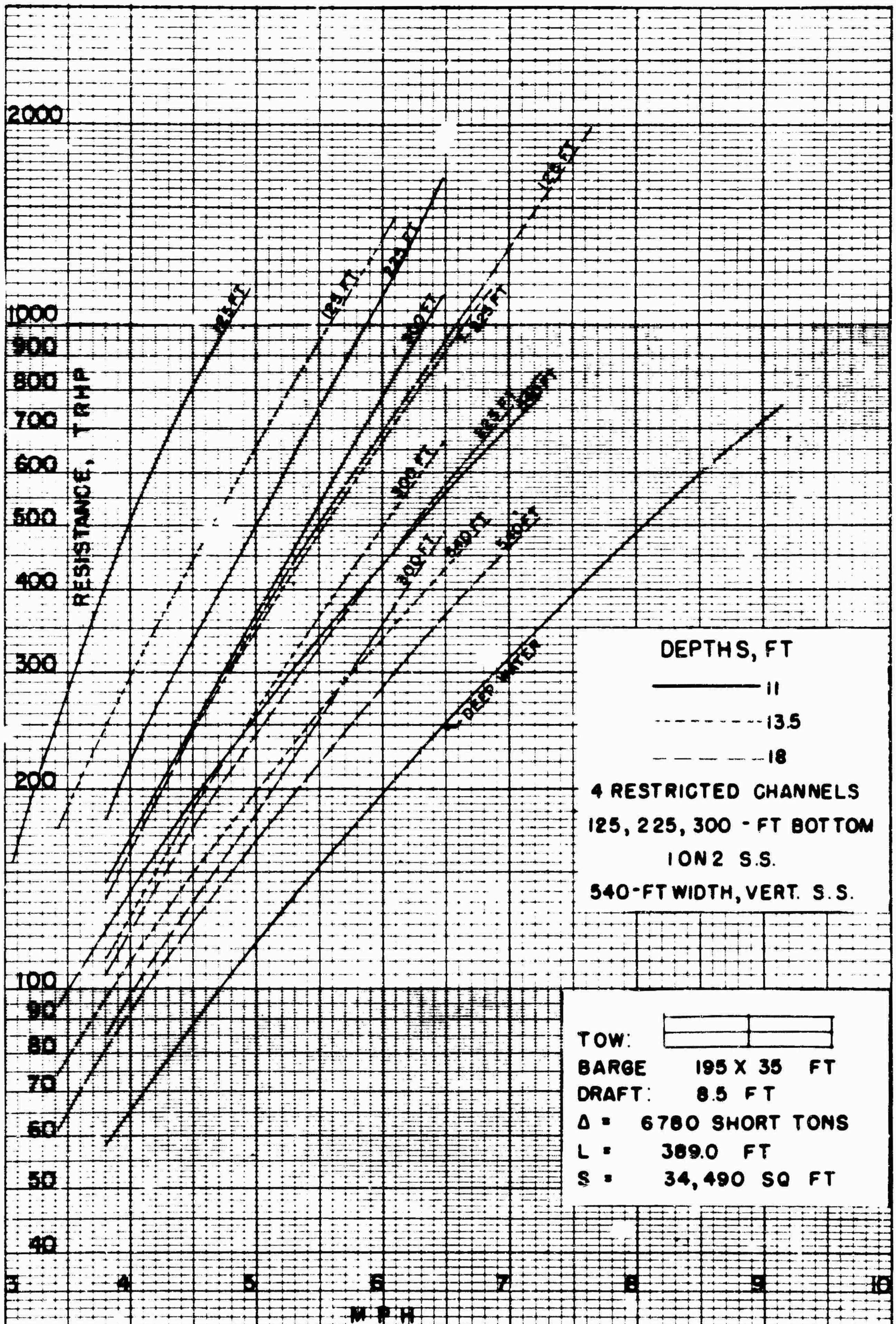
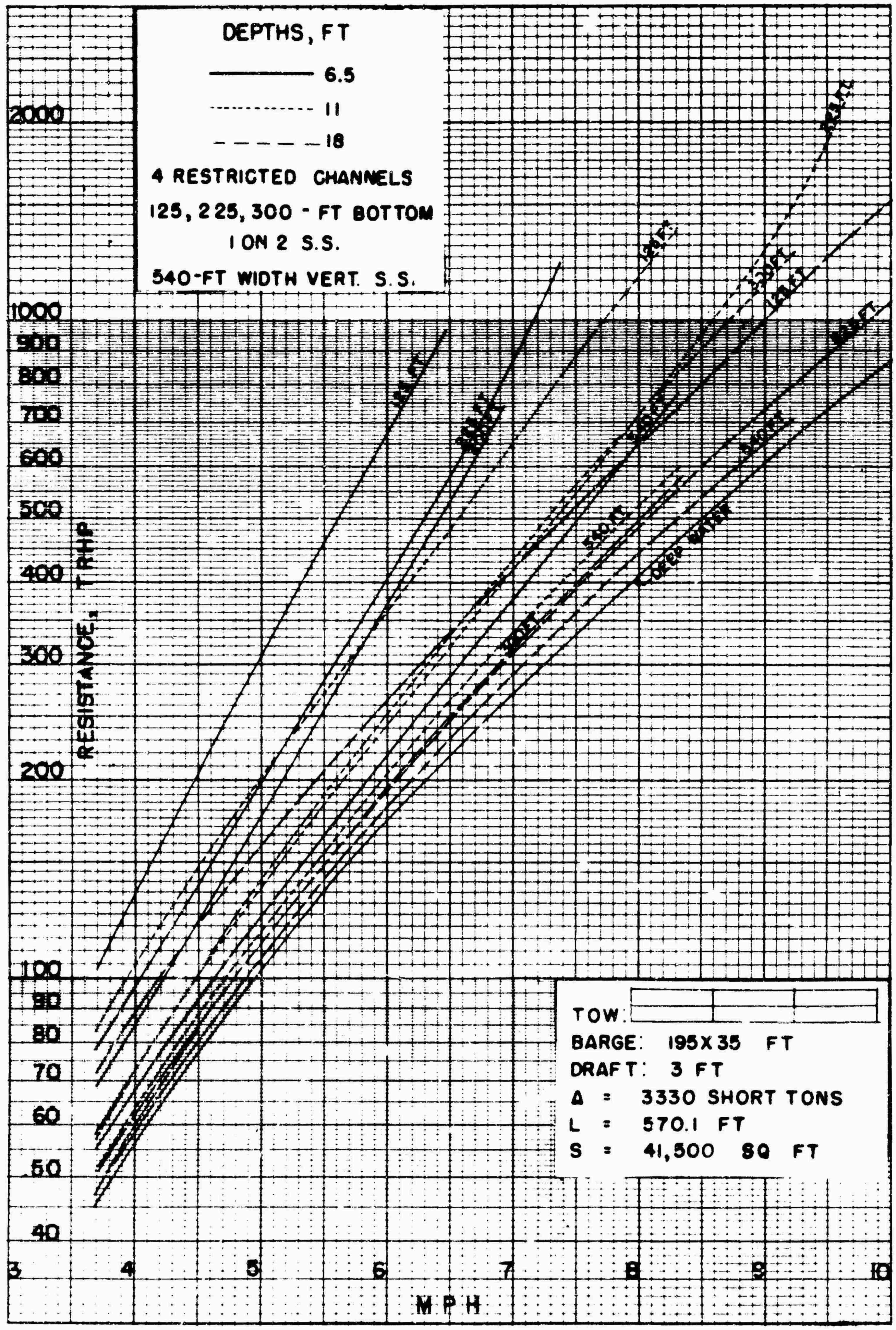
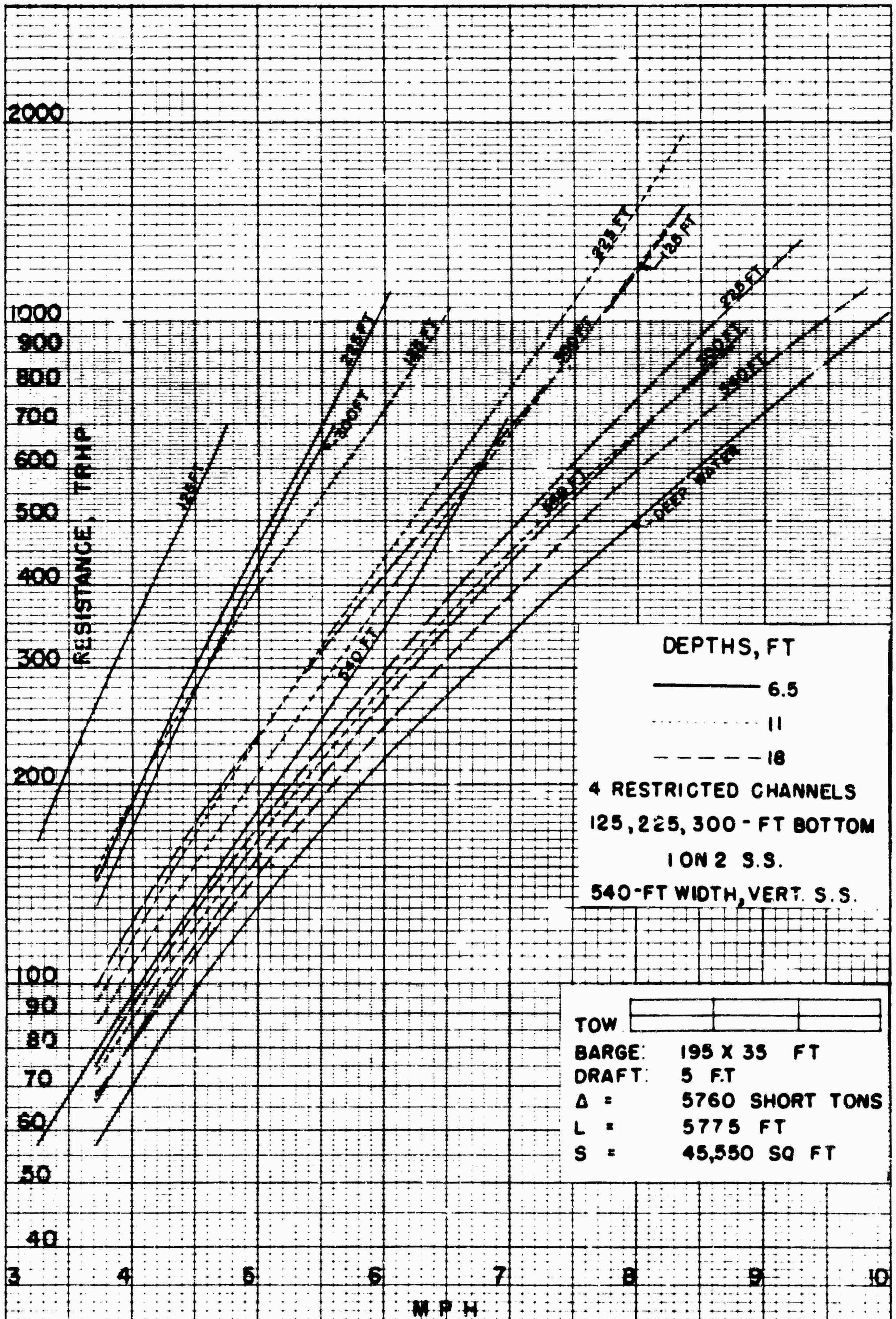

DEPTHS, FT
6.5
11
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S.S.
TOW:
BARGE: 195 X 35 FT
DRAFT: 5 FT
Δ = 3840 SHORT TONS
L = 382.5 FT
S = 30,360 SQ FT
RESISTANCE, TRHP
MPH
125 FT
225 FT
300 FT
540 FT
DEEP WATER

PLATE 6



RESISTANCE, TRHP
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
3
4
5
6
7
8
9
10
M P H
DEPTHS, FT
11
13.5
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S.S.
TOW:
BARGE 195 X 35 FT
DRAFT: 8.5 FT
Δ = 6780 SHORT TONS
L = 389.0 FT
S = 34,490 SQ FT
DEEP WATER


DEPTHS, FT
6.5
11
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH VERT. S.S.
TOW:
BARGE: 195 X 35 FT
DRAFT: 3 FT
Δ = 3330 SHORT TONS
L = 570.1 FT
S = 41,500 SQ FT
RESISTANCE, T RHP
MPH
DEEP WATER
540 FT



DEPTHS, FT
6.5
11
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S.S.
TOW
BARGE: 195 X 35 FT
DRAFT: 5 F.T
Δ = 5760 SHORT TONS
L = 5775 FT
S = 45,550 SQ FT
RESISTANCE, TRHP
M P H
DEEP WATER

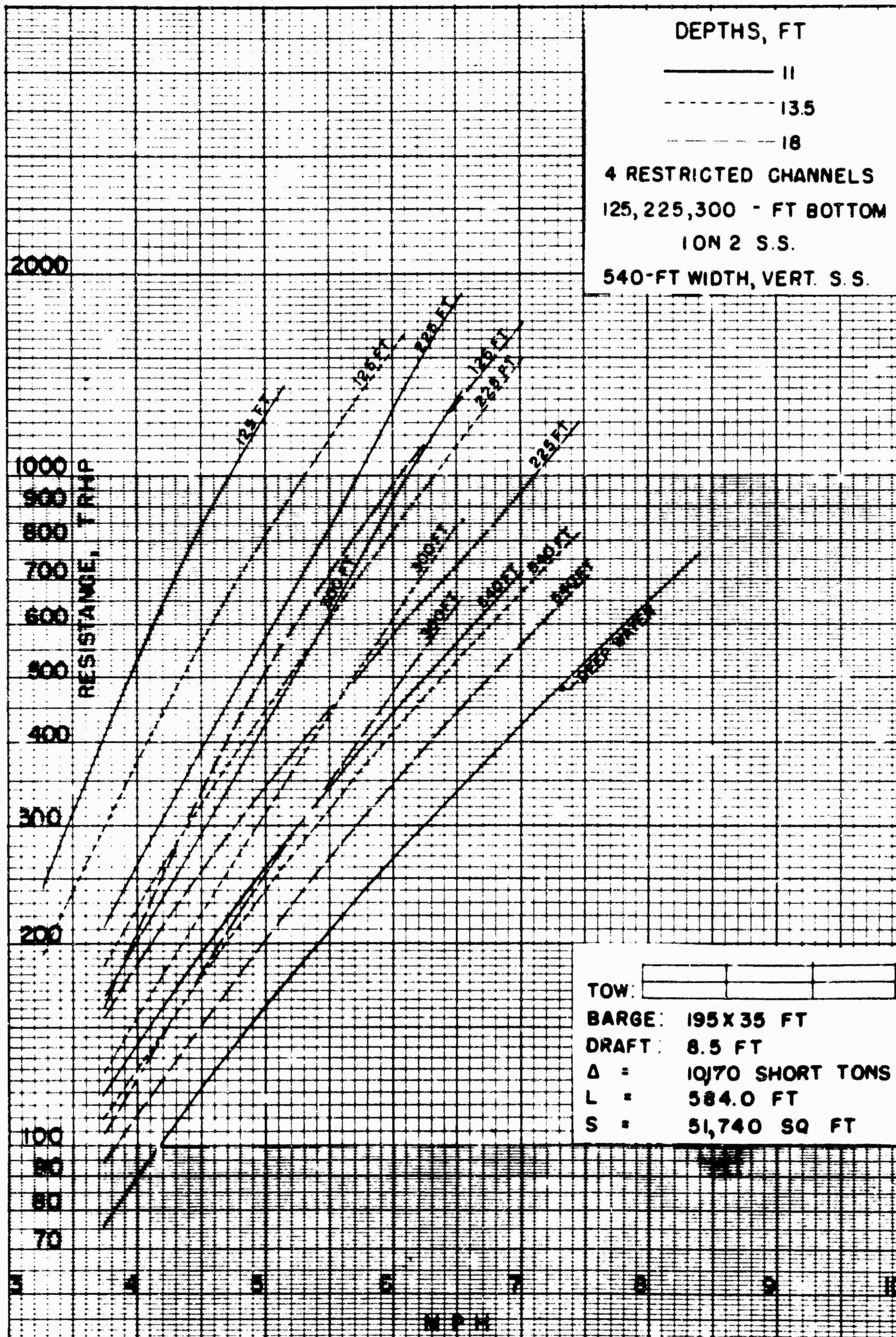
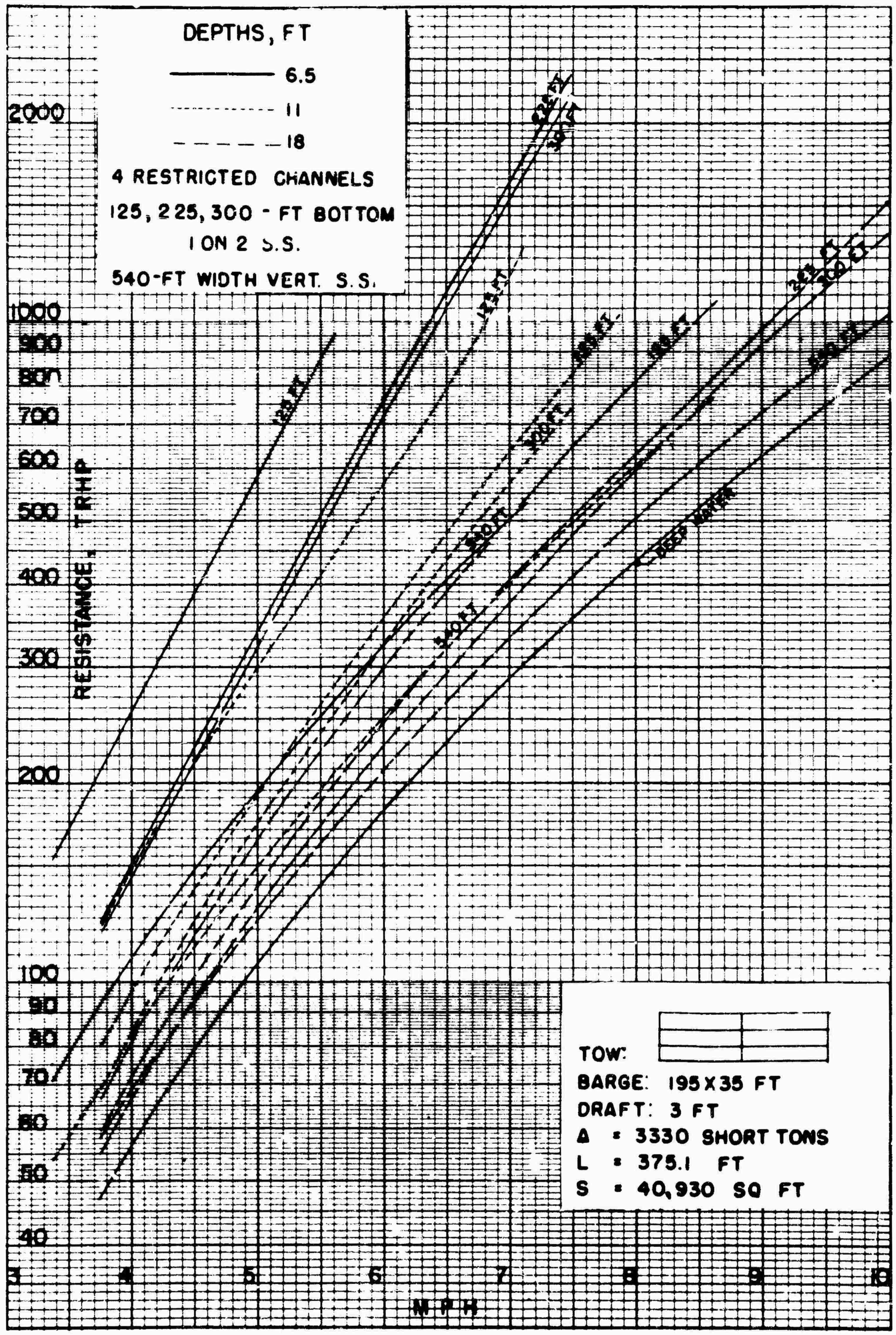
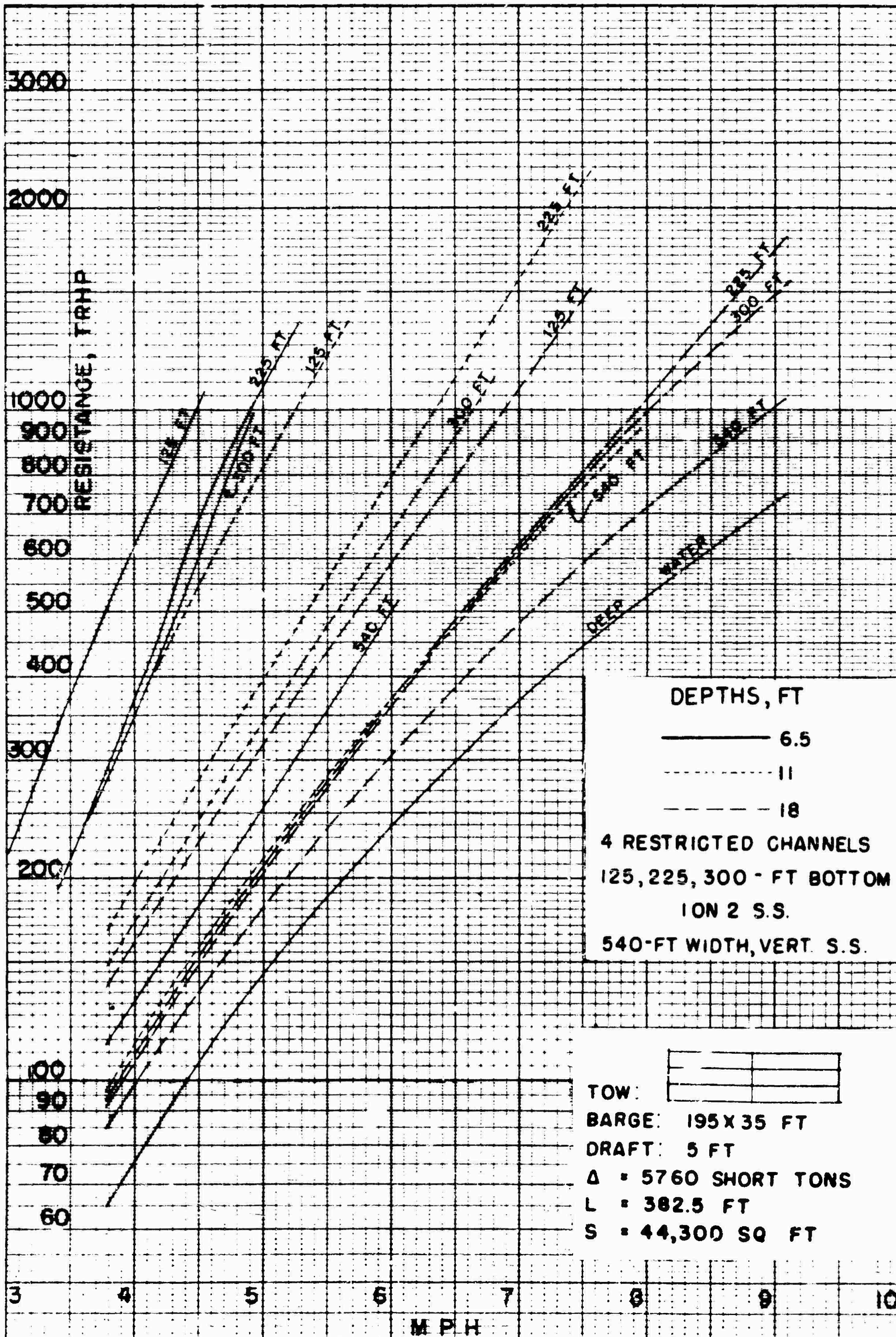

DEPTHS, FT
11
13.5
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S.S.
RESISTANCE, TRHP
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
125 FT
125 FT
225 FT
125 FT
225 FT
225 FT
300 FT
300 FT
300 FT
540 FT
540 FT
540 FT
DEEP WATER
3
4
5
6
7
8
9
10
MPH
TOW:
BARGE: 195 X 35 FT
DRAFT: 8.5 FT
Δ = 10,170 SHORT TONS
L = 584.0 FT
S = 51,740 SQ FT

PLATE 10



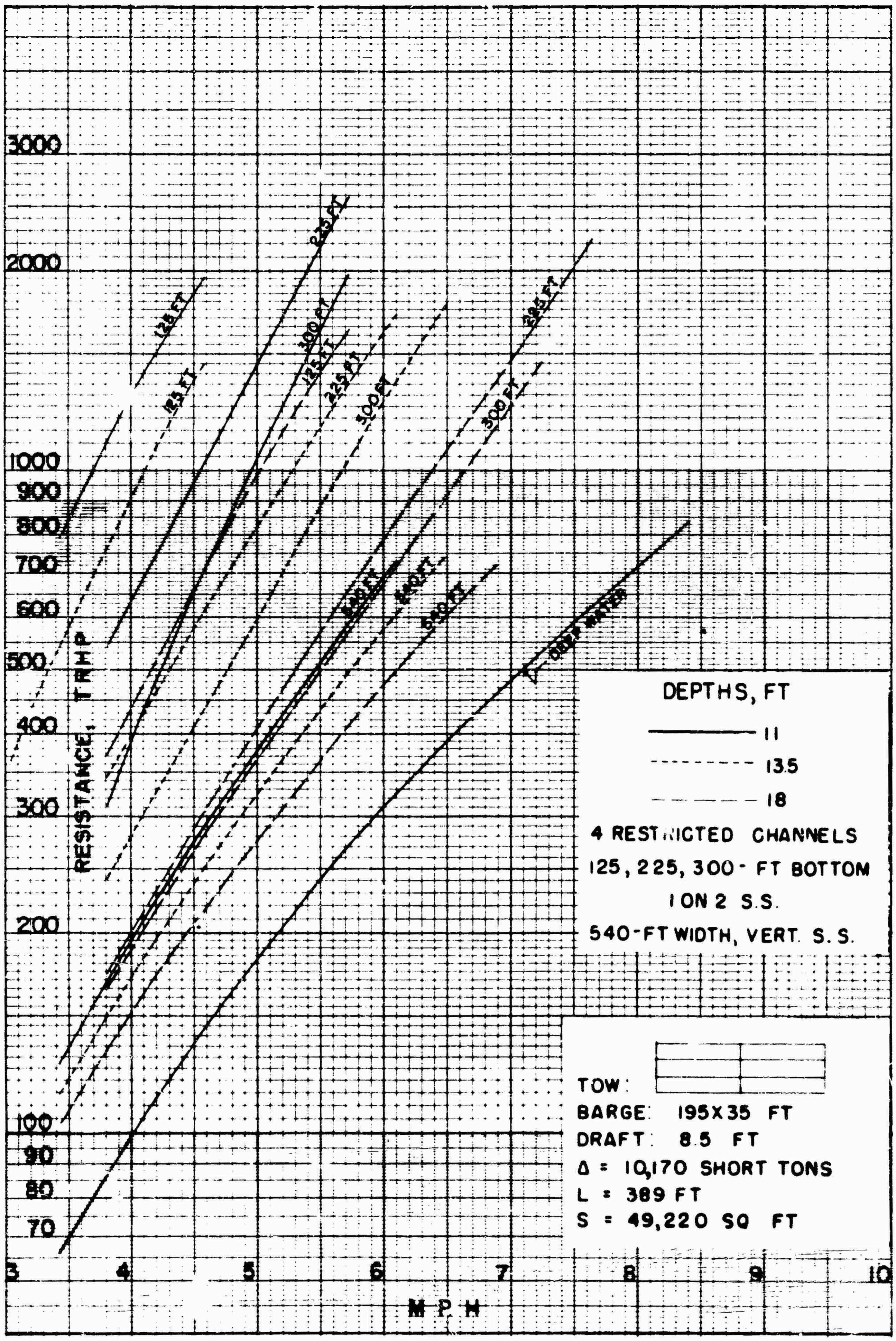
DEPTHS, FT
6.5
11
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH VERT. S.S.
TOW:
BARGE: 195 X 35 FT
DRAFT: 3 FT
Δ = 3330 SHORT TONS
L = 375.1 FT
S = 40,930 SQ FT
RESISTANCE, TRHP
M P H
DEEP WATER

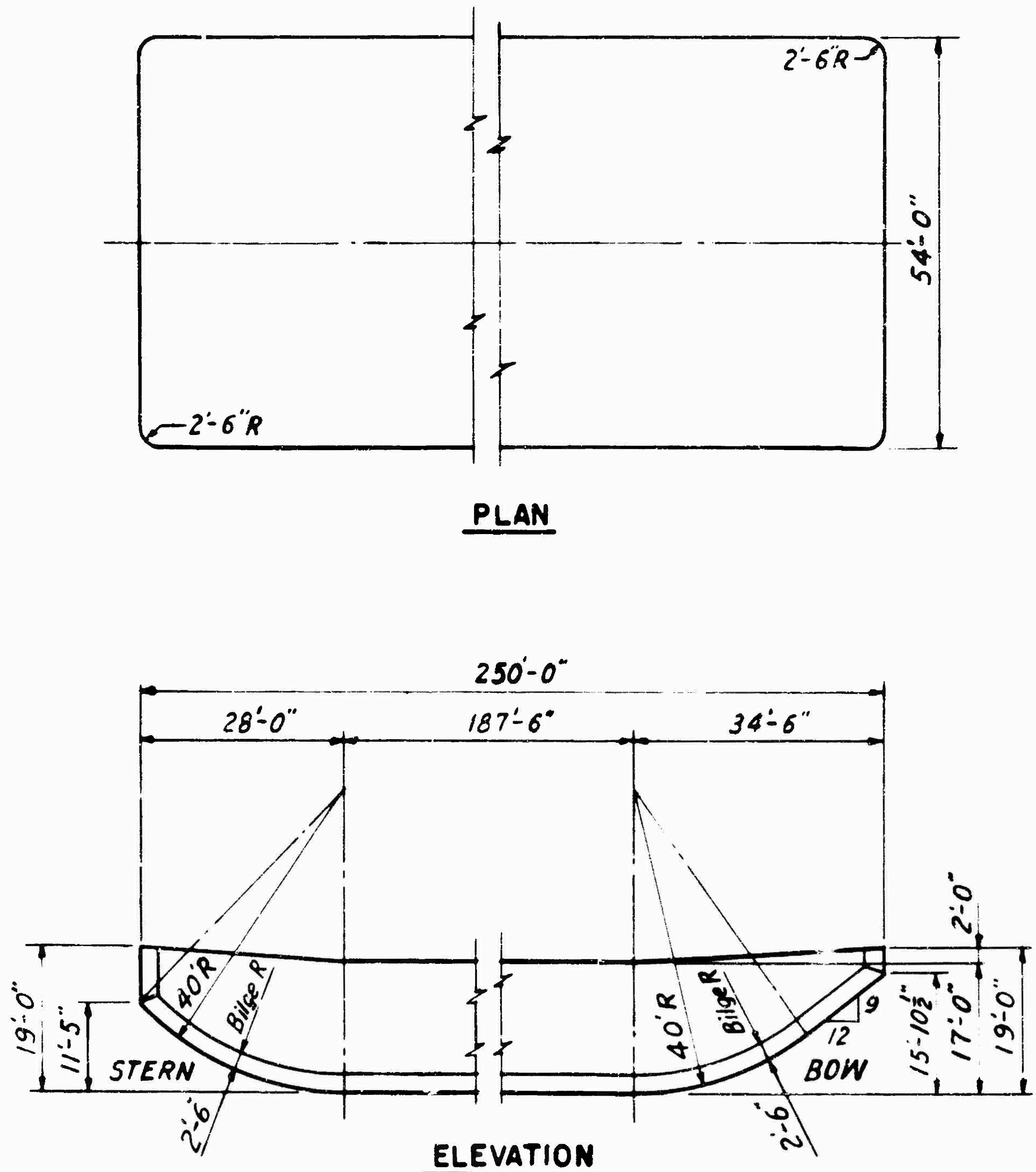
PLATE 11



RESISTANCE, TRHP
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
3
4
5
6
7
8
9
10
MPH
125 FT
225 FT
125 FT
300 FT
225 FT
125 FT
300 FT
540 FT
225 FT
300 FT
540 FT
540 FT
DEEP WATER
DEPTHS, FT
6.5
11
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S.S.
TOW:
BARGE: 195 X 35 FT
DRAFT: 5 FT
Δ = 5760 SHORT TONS
L = 382.5 FT
S = 44,300 SQ FT

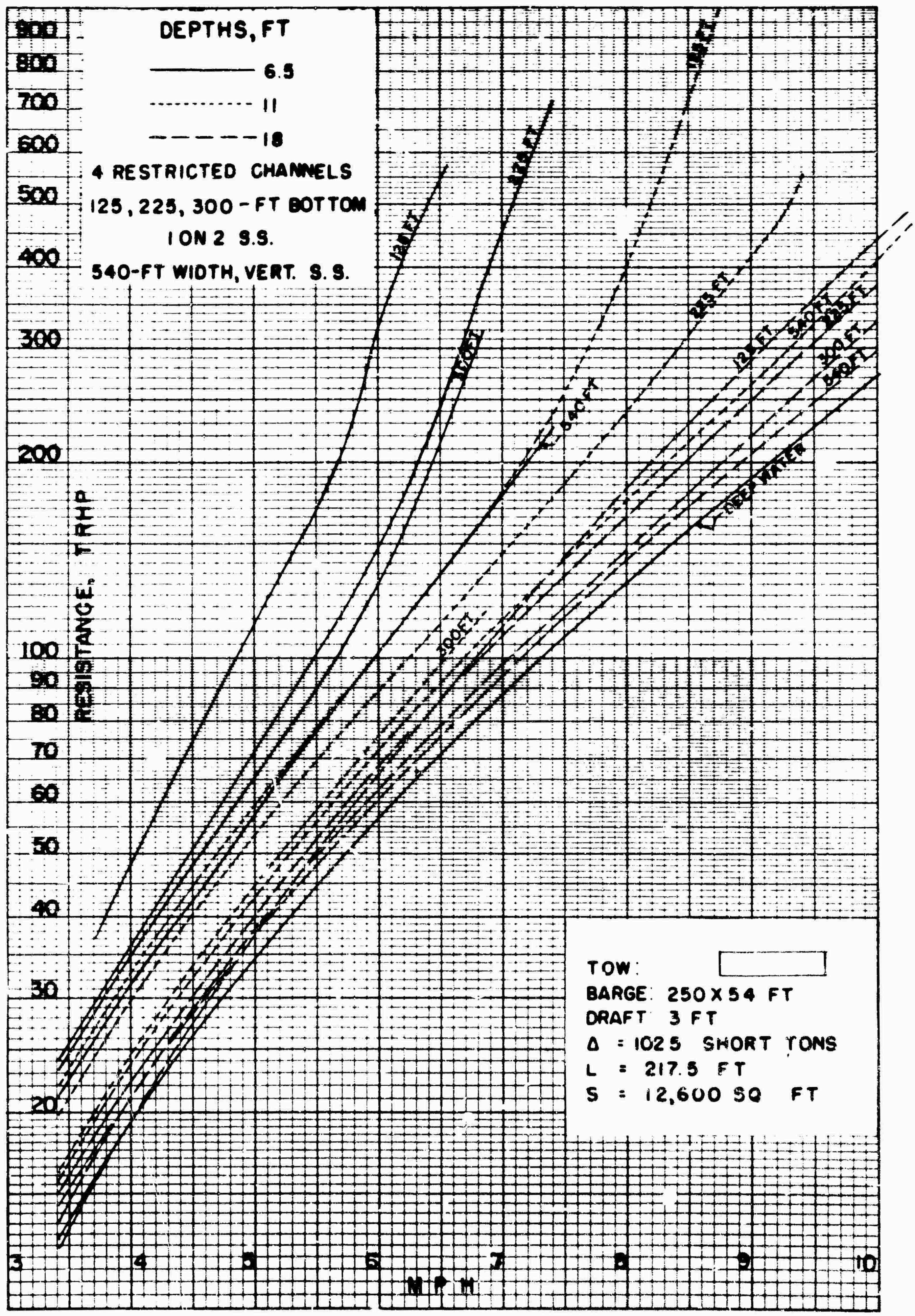
PLATE 12

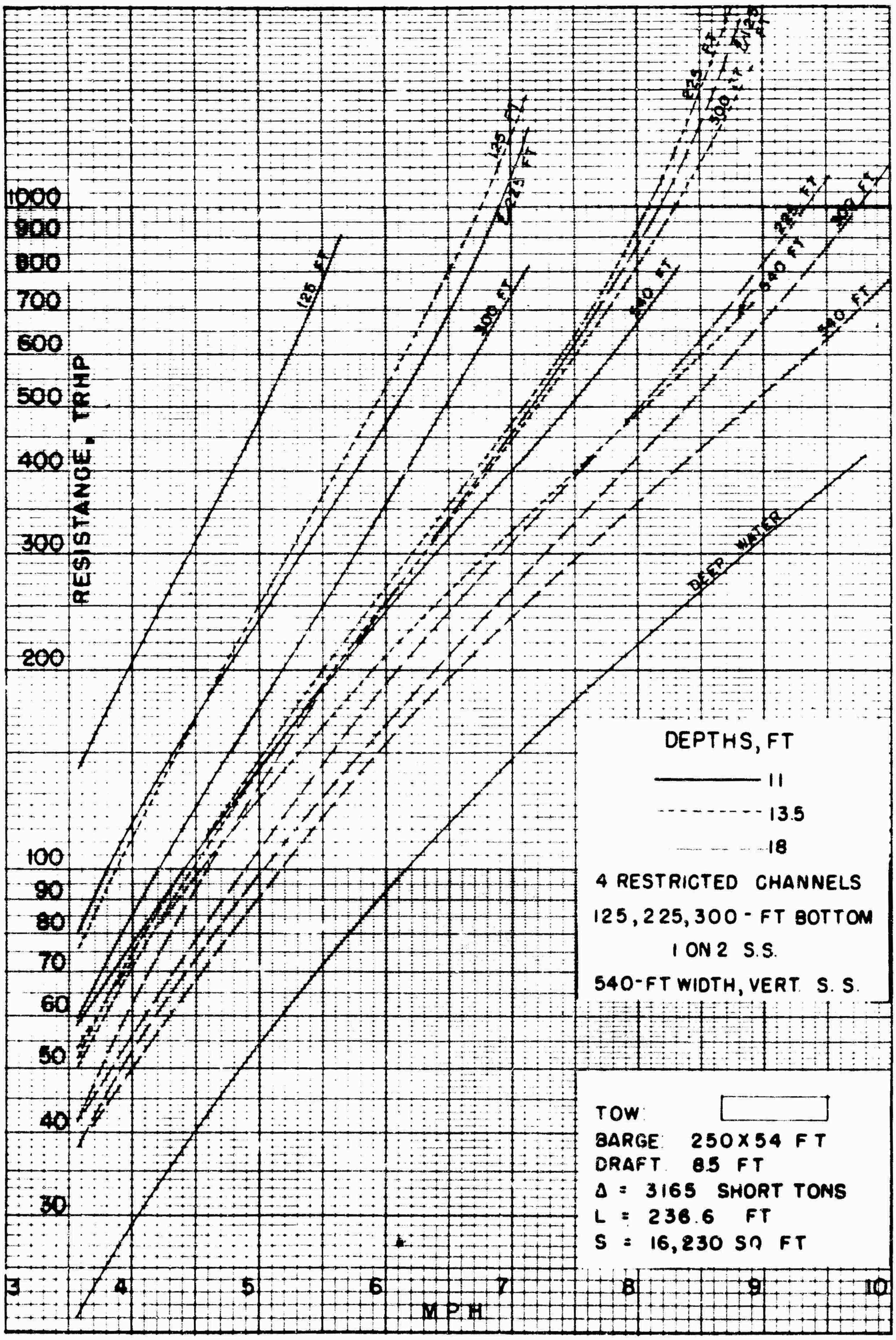

DEPTHS, FT
11
13.5
18
4 RESTRICTED CHANNELS
125, 225, 300- FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S.S.
TOW:
BARGE: 195X35 FT
DRAFT: 8.5 FT
Δ = 10,170 SHORT TONS
L = 389 FT
S = 49,220 SQ FT
RESISTANCE, TRHP
M P H
DEEP WATER
125 FT
225 FT
300 FT
540 FT
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
3
4
5
6
7
8
9
10



NOTE:
Design of barge envisioned for use on large canals.

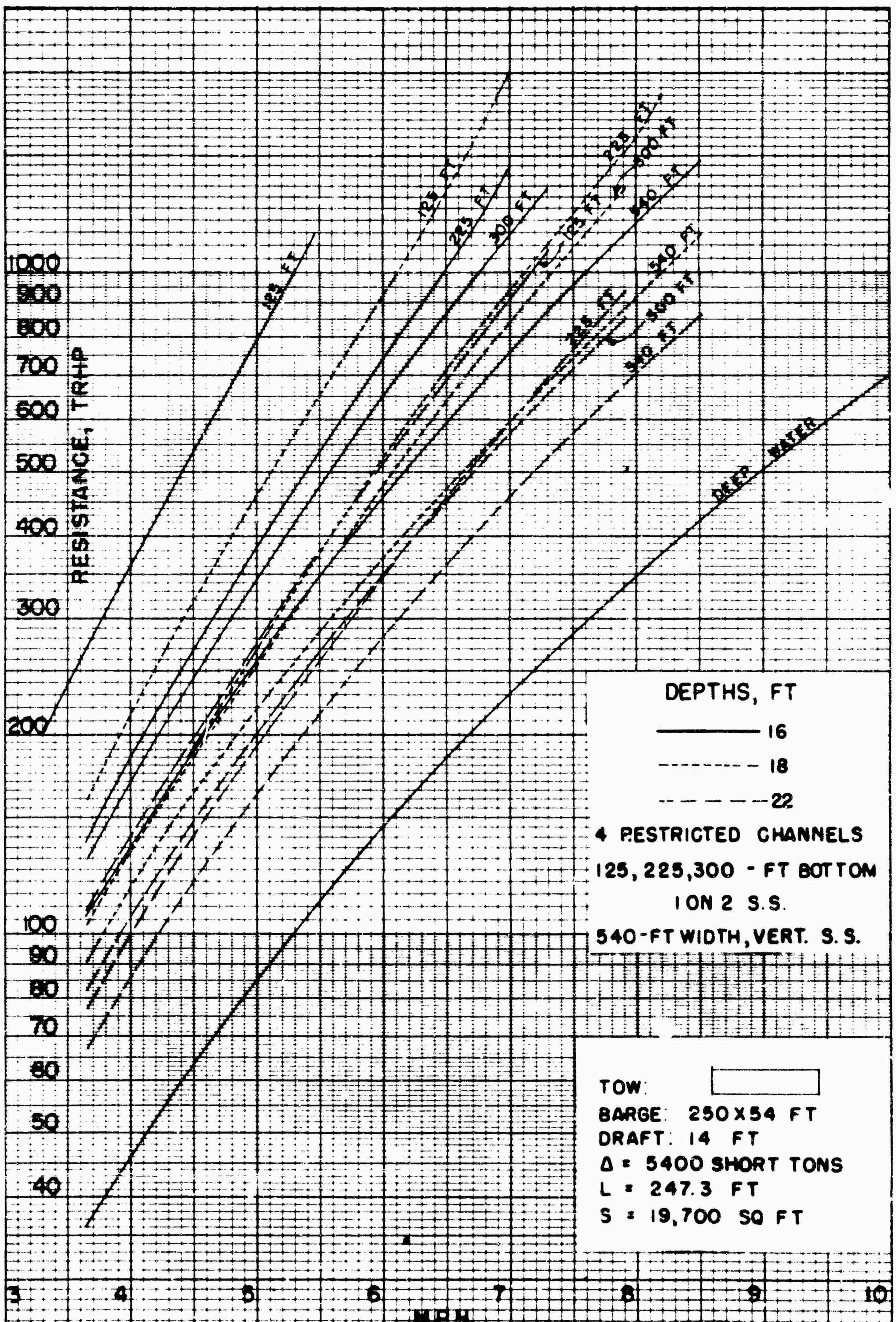
250-FT X 54-FT BARGE FOR TESTS ON PLATES 15 TO 20 INCL.

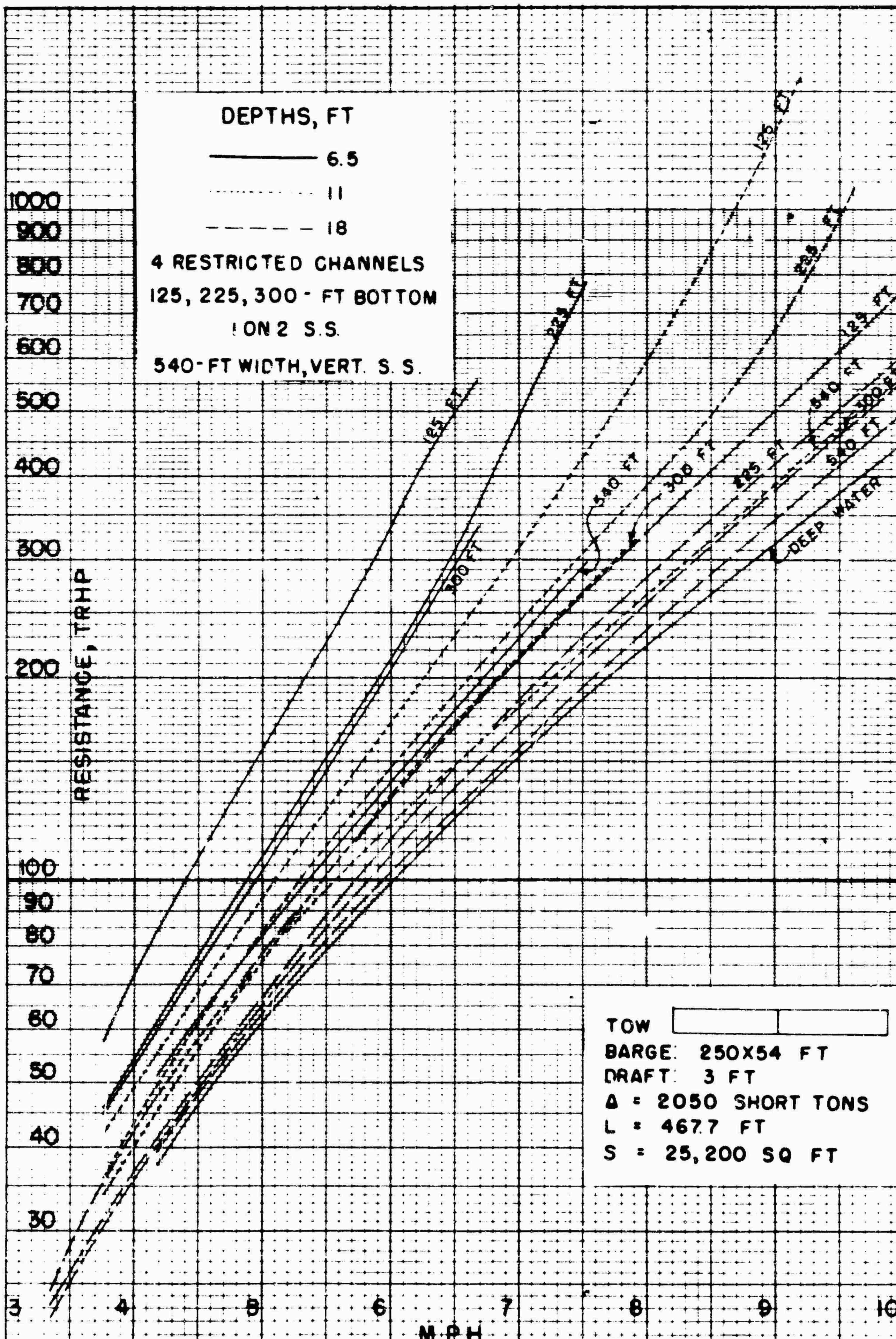

DEPTHS, FT
6.5
11
18
4 RESTRICTED CHANNELS
125, 225, 300-FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S.S.
RESISTANCE, TRHP
MPH
TOW:
BARGE: 250 X 54 FT
DRAFT 3 FT
Δ = 1025 SHORT TONS
L = 217.5 FT
S = 12,600 SQ FT
125 FT
225 FT
300 FT
540 FT
DEEP WATER



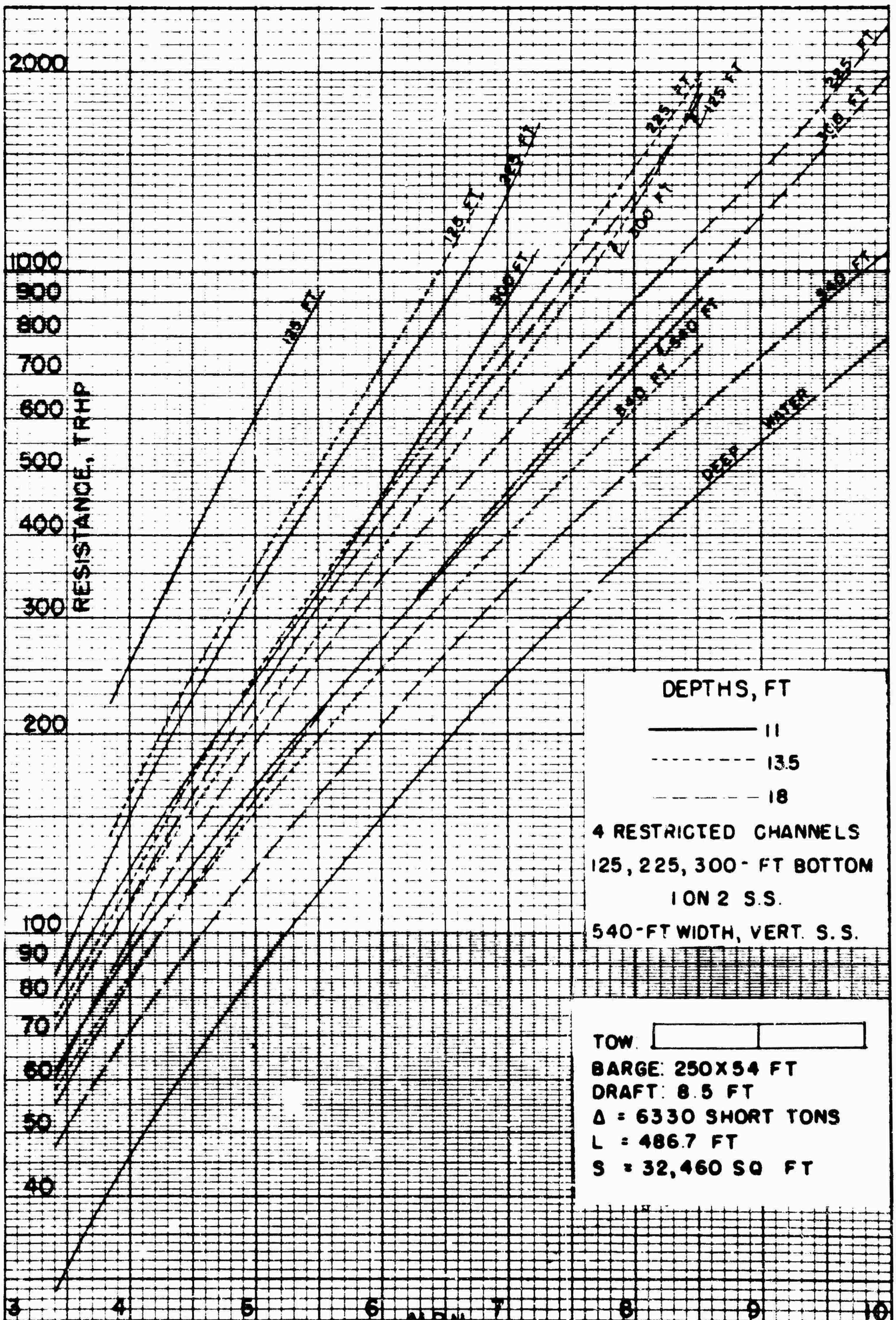
RESISTANCE, TRHP
MPH
125 FT
225 FT
300 FT
540 FT
DEEP WATER
DEPTHS, FT
11
13.5
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S. S.
TOW
BARGE 250 X 54 FT
DRAFT 8.5 FT
Δ = 3165 SHORT TONS
L = 236.6 FT
S = 16,230 SQ FT

PLATE 16


RESISTANCE, TRHP
MPH
DEPTHS, FT
16
18
22
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S.S.
TOW:
BARGE: 250 X 54 FT
DRAFT: 14 FT
Δ = 5400 SHORT TONS
L = 247.3 FT
S = 19,700 SQ FT
DEEP WATER
125 FT
225 FT
300 FT
540 FT



DEPTHS, FT
6.5
11
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S. S.
125 FT
225 FT
300 FT
540 FT
DEEP WATER
RESISTANCE, TRHP
MPH
TOW
BARGE: 250X54 FT
DRAFT: 3 FT
Δ = 2050 SHORT TONS
L = 467.7 FT
S = 25,200 SQ FT



RESISTANCE, TRHP
MPH
DEPTHS, FT
11
13.5
18
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S.S.
TOW
BARGE: 250X54 FT
DRAFT: 8.5 FT
Δ = 6330 SHORT TONS
L = 486.7 FT
S = 32,460 SQ FT
DEEP WATER

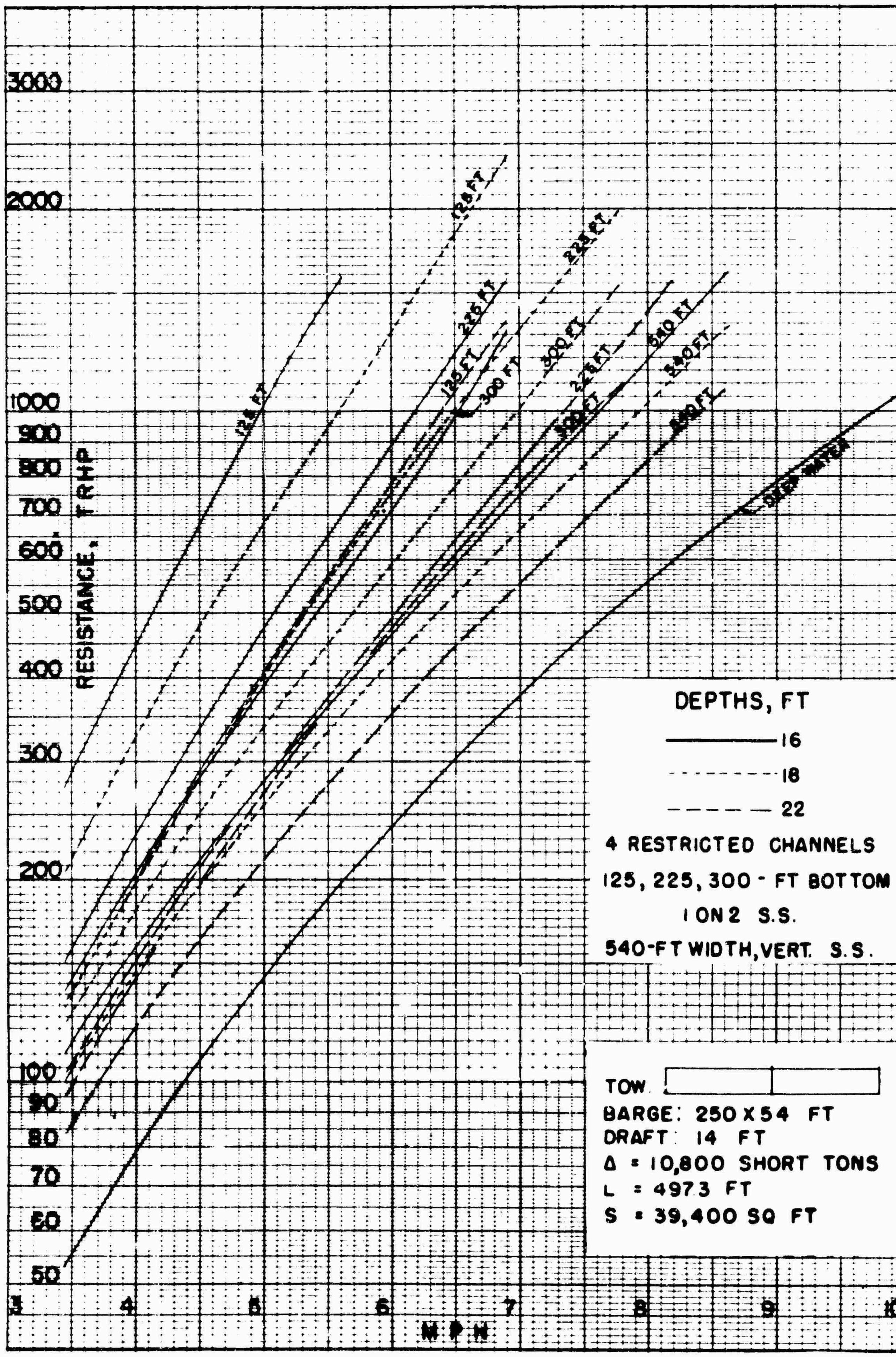
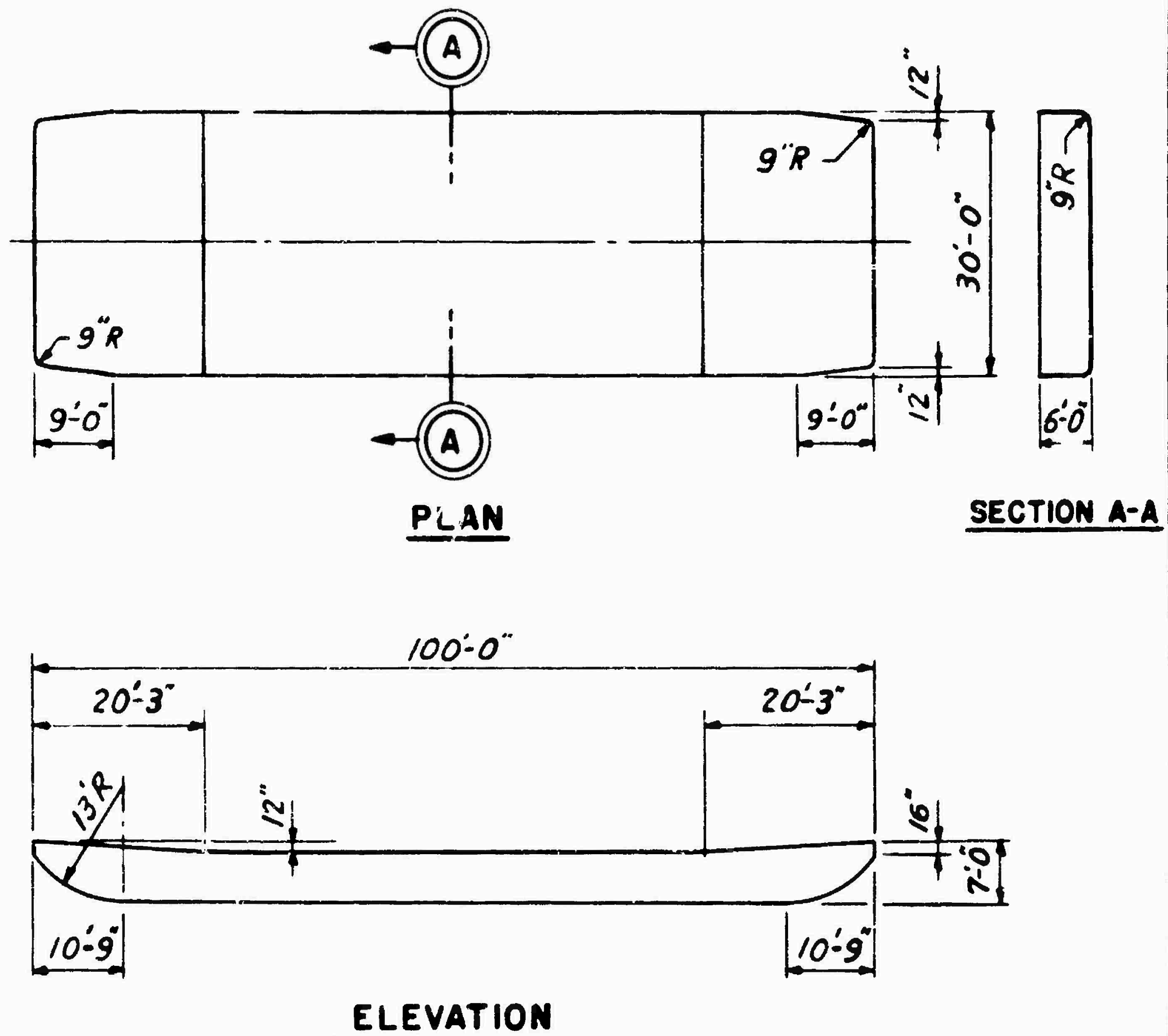
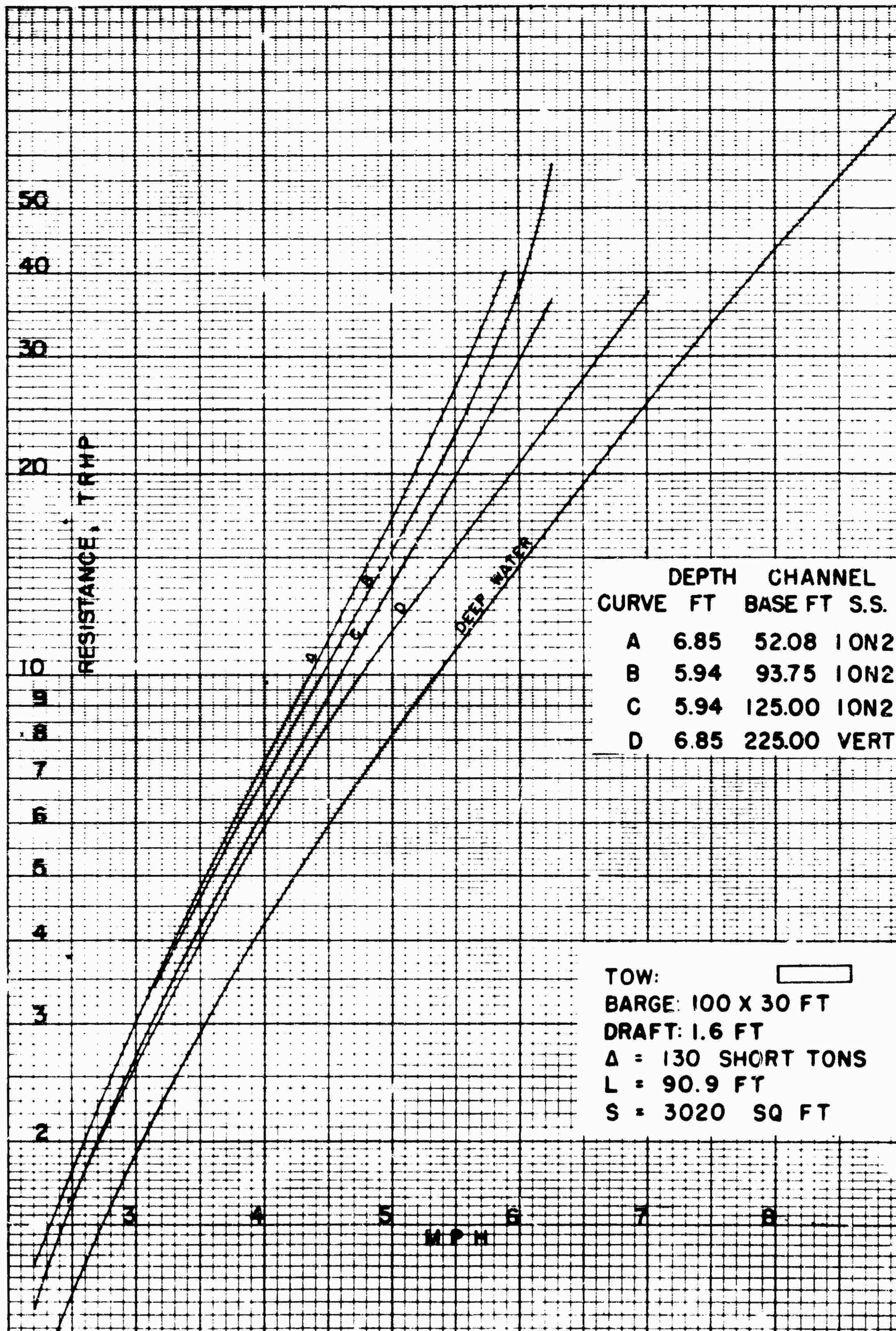

3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
RESISTANCE, TRHP
3
4
5
6
7
8
9
10
M P H
125 FT
125 FT
225 FT
225 FT
125 FT
300 FT
300 FT
225 FT
300 FT
540 FT
540 FT
540 FT
DEEP WATER
DEPTHS, FT
16
18
22
4 RESTRICTED CHANNELS
125, 225, 300 - FT BOTTOM
1 ON 2 S.S.
540-FT WIDTH, VERT. S.S.
TOW
BARGE: 250 X 54 FT
DRAFT: 14 FT
Δ = 10,800 SHORT TONS
L = 497.3 FT
S = 39,400 SQ FT

PLATE 20



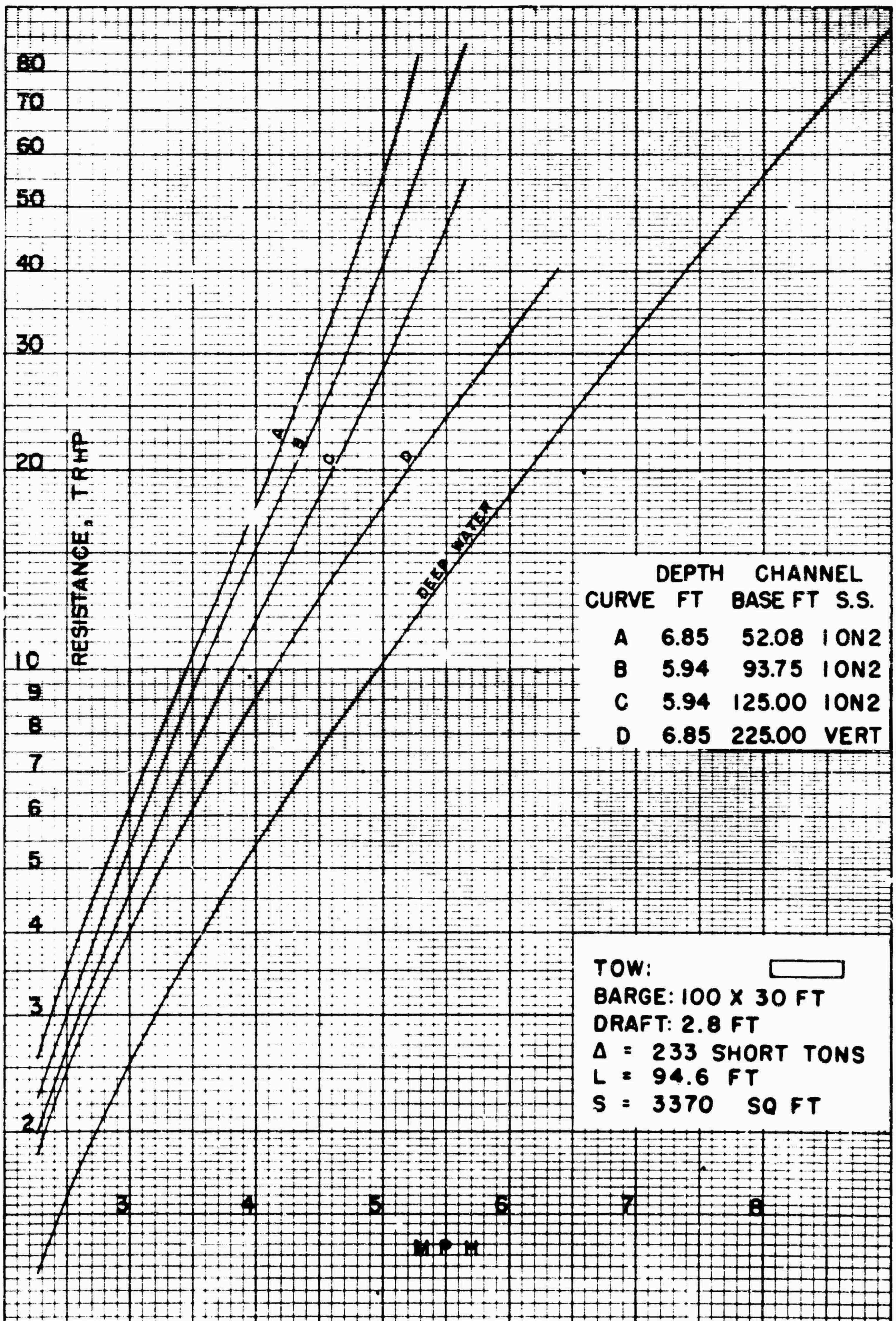
NOTE:
Barge used in tow resistance studies, 1936, on Illinois and Mississippi canal, Illinois.

100-FT X 30-FT BARGE
FOR TESTS ON
PLATES 22 TO 27 INCL.



50
40
30
20
10
9
8
7
6
5
4
3
2
RESISTANCE, TRHP
3
4
5
6
7
8
MPH
A
B
C
D
DEEP WATER
CURVE | DEPTH FT | CHANNEL BASE FT | S.S.
A | 6.85 | 52.08 | 1 ON 2
B | 5.94 | 93.75 | 1 ON 2
C | 5.94 | 125.00 | 1 ON 2
D | 6.85 | 225.00 | VERT
TOW:
BARGE: 100 X 30 FT
DRAFT: 1.6 FT
Δ = 130 SHORT TONS
L = 90.9 FT
S = 3020 SQ FT

PLATE 22


RESISTANCE, TRHP
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
3
4
5
6
7
8
M P H
A
B
C
D
DEEP WATER
DEPTH CHANNEL
CURVE FT BASE FT S.S.
A 6.85 52.08 1 ON 2
B 5.94 93.75 1 ON 2
C 5.94 125.00 1 ON 2
D 6.85 225.00 VERT
TOW:
BARGE: 100 X 30 FT
DRAFT: 2.8 FT
Δ = 233 SHORT TONS
L = 94.6 FT
S = 3370 SQ FT

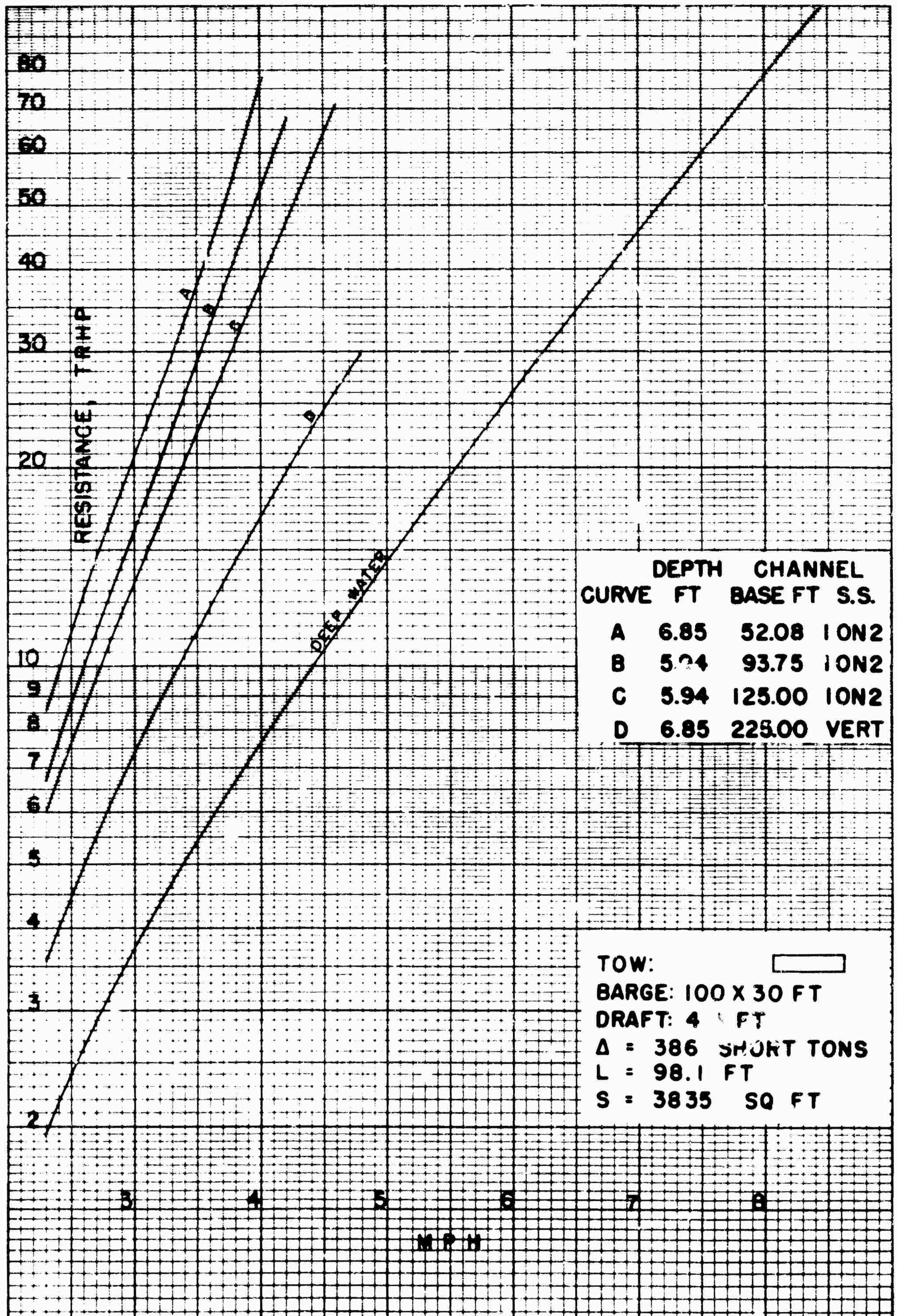
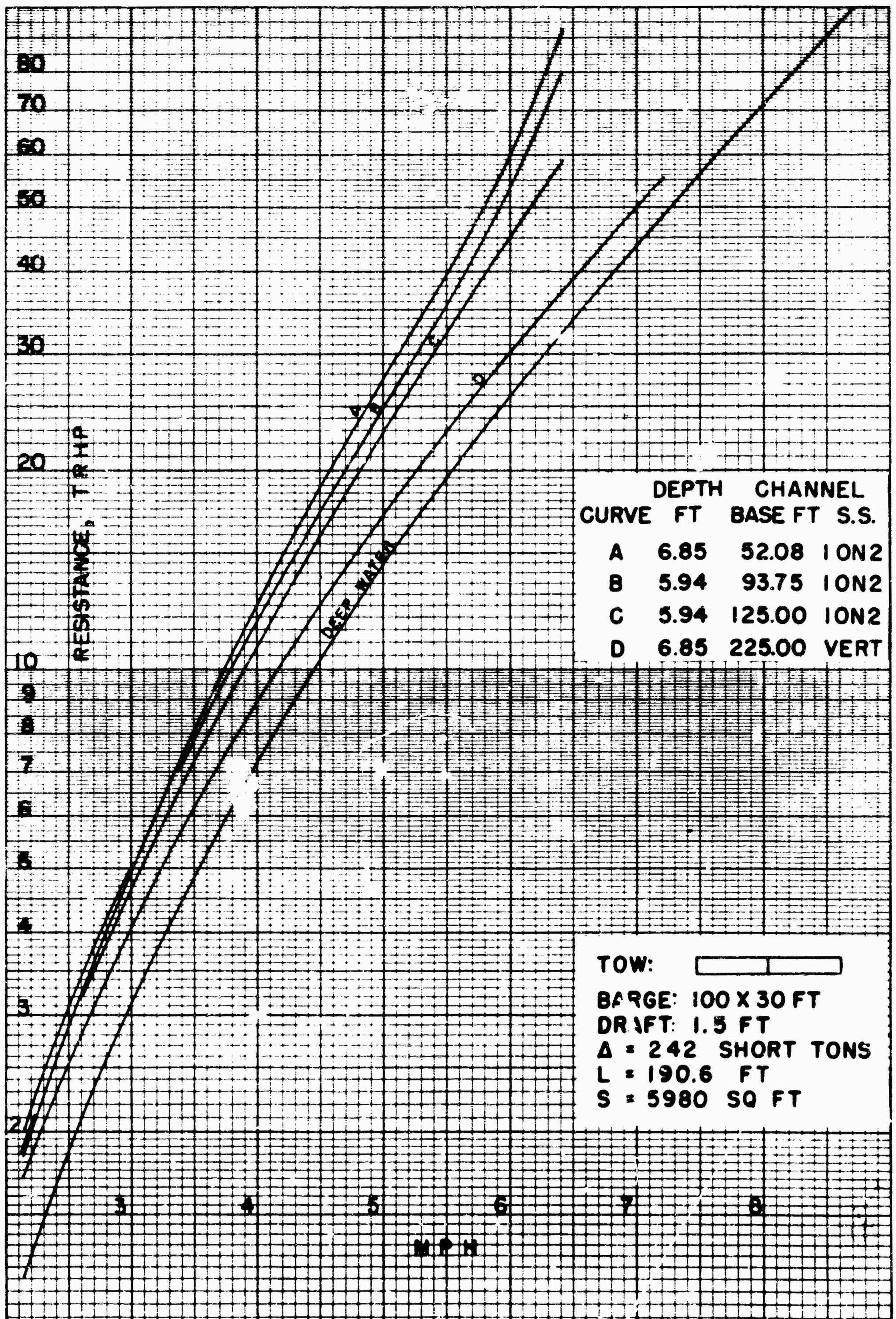

RESISTANCE, TRHP
M P H
A
B
C
D
DEEP WATER
CURVE DEPTH FT CHANNEL BASE FT S.S.
A 6.85 52.08 1 ON 2
B 93.75 1 ON 2
C 5.94 125.00 1 ON 2
D 6.85 225.00 VERT
TOW:
BARGE: 100 X 30 FT
DRAFT: 4 FT
Δ = 386 SHORT TONS
L = 98.1 FT
S = 3835 SQ FT

PLATE 24


RESISTANCE, T R HP
MPH
A
B
C
D
DEEP WATER
DEPTH CHANNEL
CURVE FT BASE FT S.S.
A 6.85 52.08 1 ON 2
B 5.94 93.75 1 ON 2
C 5.94 125.00 1 ON 2
D 6.85 225.00 VERT
TOW:
BARGE: 100 X 30 FT
DRAFT: 1.5 FT
Δ = 242 SHORT TONS
L = 190.6 FT
S = 5980 SQ FT

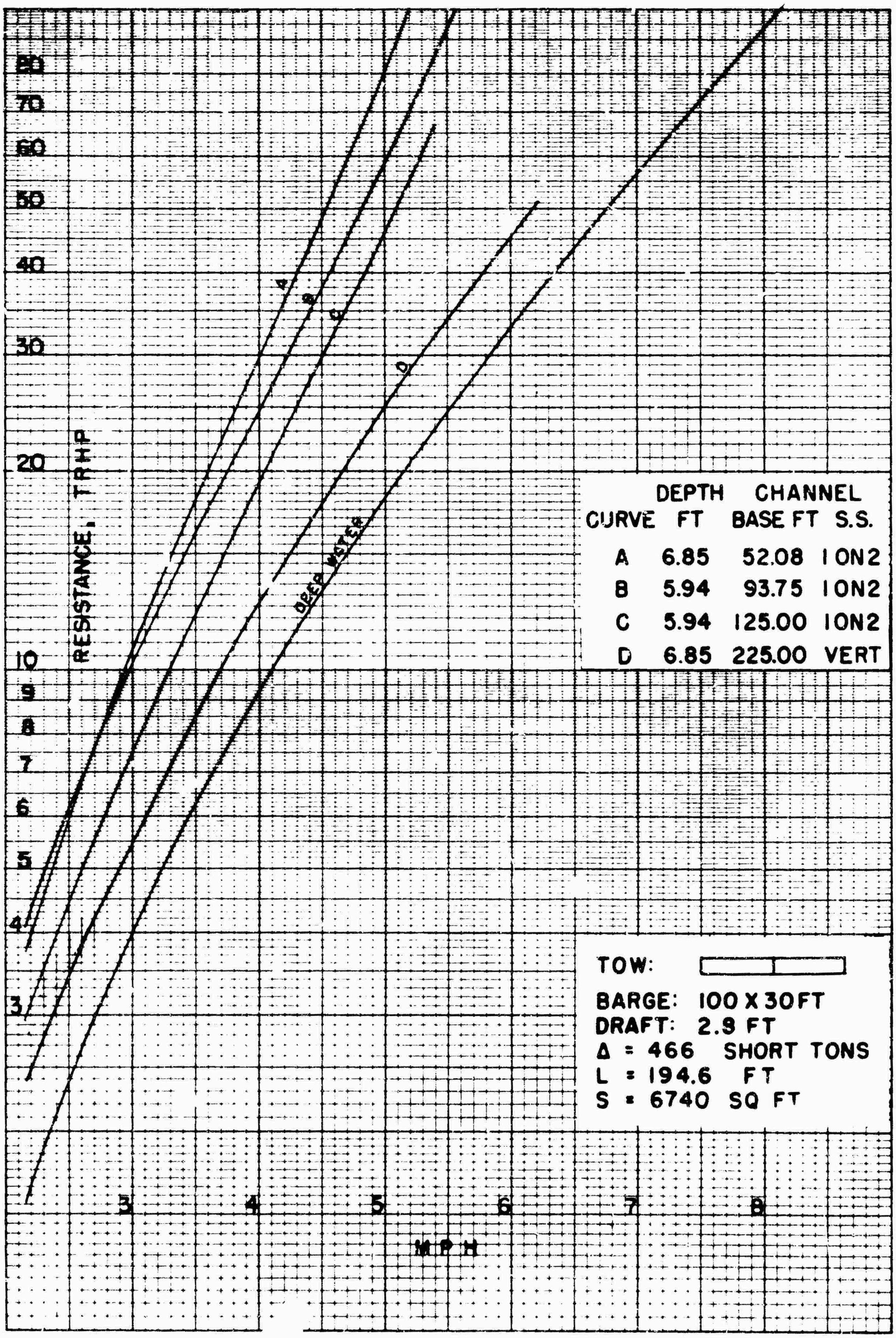
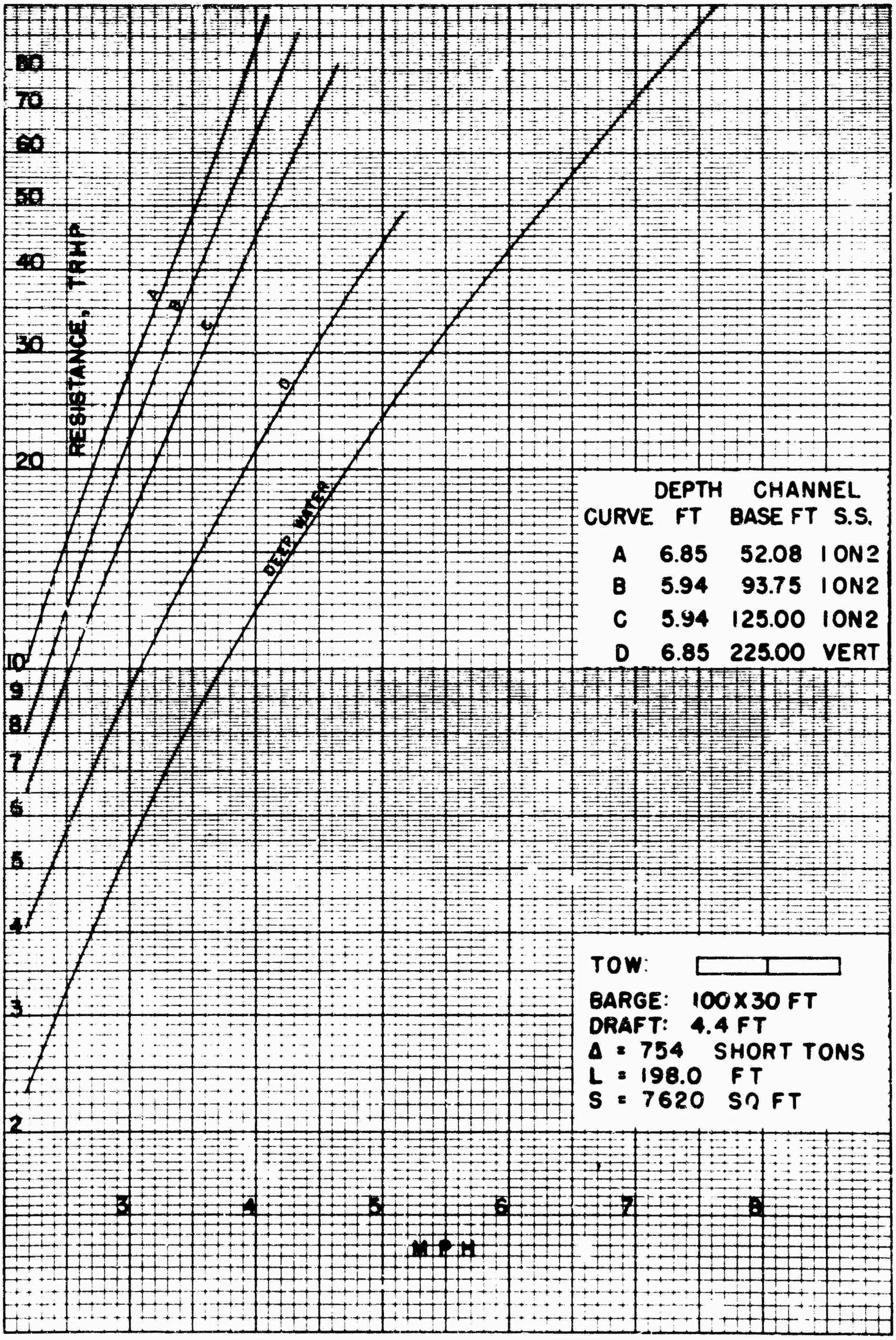
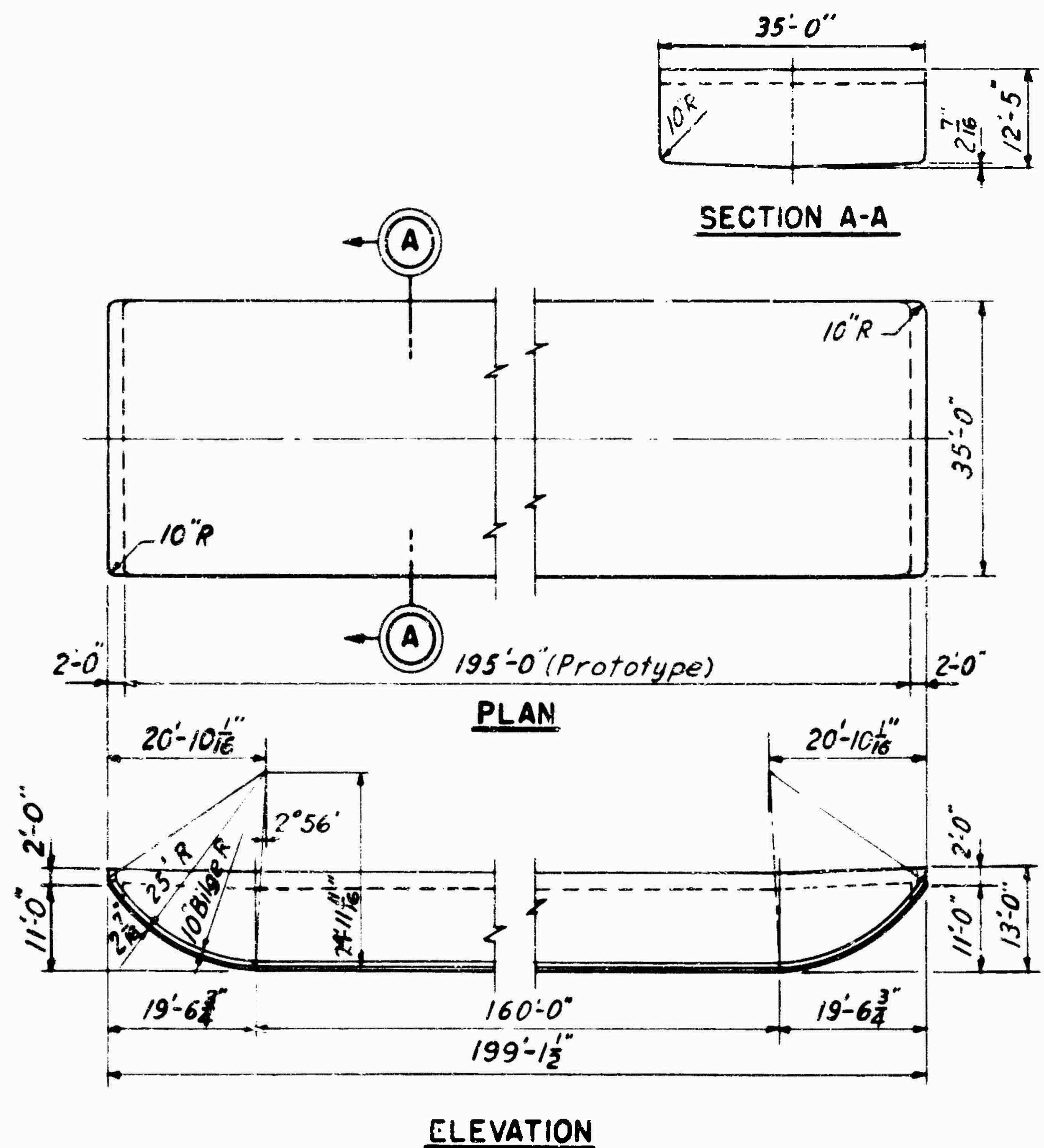

RESISTANCE, TRHP
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
A
B
C
D
DEEP WATER
3
4
5
6
7
8
MPH
CURVE | DEPTH FT | CHANNEL BASE FT | S.S.
A | 6.85 | 52.08 | 1 ON 2
B | 5.94 | 93.75 | 1 ON 2
C | 5.94 | 125.00 | 1 ON 2
D | 6.85 | 225.00 | VERT
TOW:
BARGE: 100 X 30 FT
DRAFT: 2.9 FT
Δ = 466 SHORT TONS
L = 194.6 FT
S = 6740 SQ FT

PLATE 26


RESISTANCE, TRHP
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
A
B
C
D
DEEP WATER
3
4
5
6
7
8
MPH
DEPTH CHANNEL
CURVE FT BASE FT S.S.
A 6.85 52.08 1 ON 2
B 5.94 93.75 1 ON 2
C 5.94 125.00 1 ON 2
D 6.85 225.00 VERT
TOW:
BARGE: 100 X 30 FT
DRAFT: 4.4 FT
Δ = 754 SHORT TONS
L = 198.0 FT
S = 7620 SQ FT

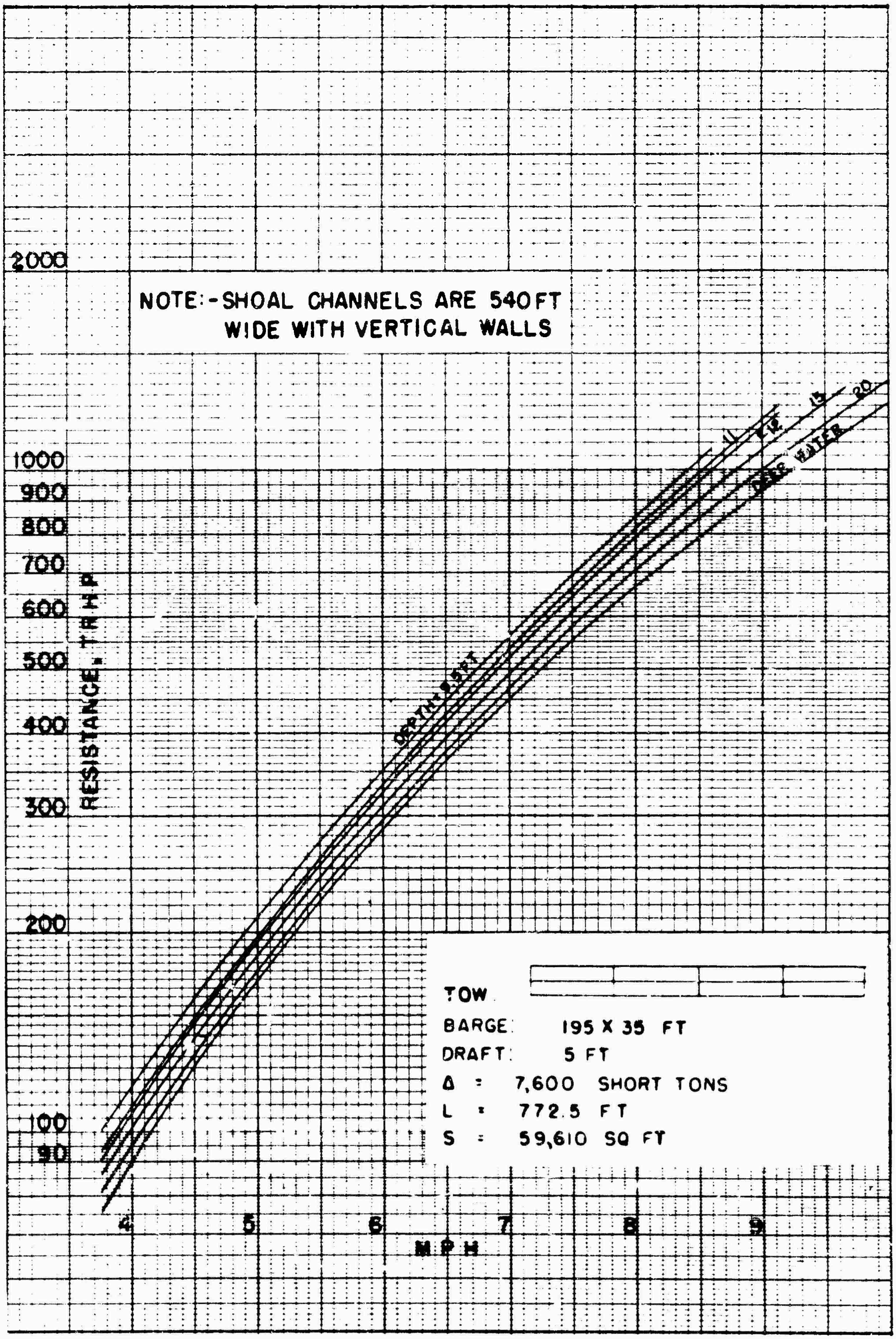


NOTE:

Length and depth of 195 FT X 35 FT barge extended for tests at drafts of 9.5 ft. and 10.5 ft., Plates 32 and 33.

Basic barge design from ST. Louis Shipbuilding and Steel CO.

195-FT X 35-FT OIL BARGE MODIFIED FOR TESTS ON PLATES 29 TO 33 INCL.


NOTE:-SHOAL CHANNELS ARE 540 FT
WIDE WITH VERTICAL WALLS
2000
1000
900
800
700
600
500
400
300
200
100
90
RESISTANCE, TR H.P.
11
12
15
20
WATER
TOW
BARGE: 195 X 35 FT
DRAFT: 5 FT
Δ = 7,600 SHORT TONS
L = 772.5 FT
S = 59,610 SQ FT
4
5
6
7
8
9
MPH

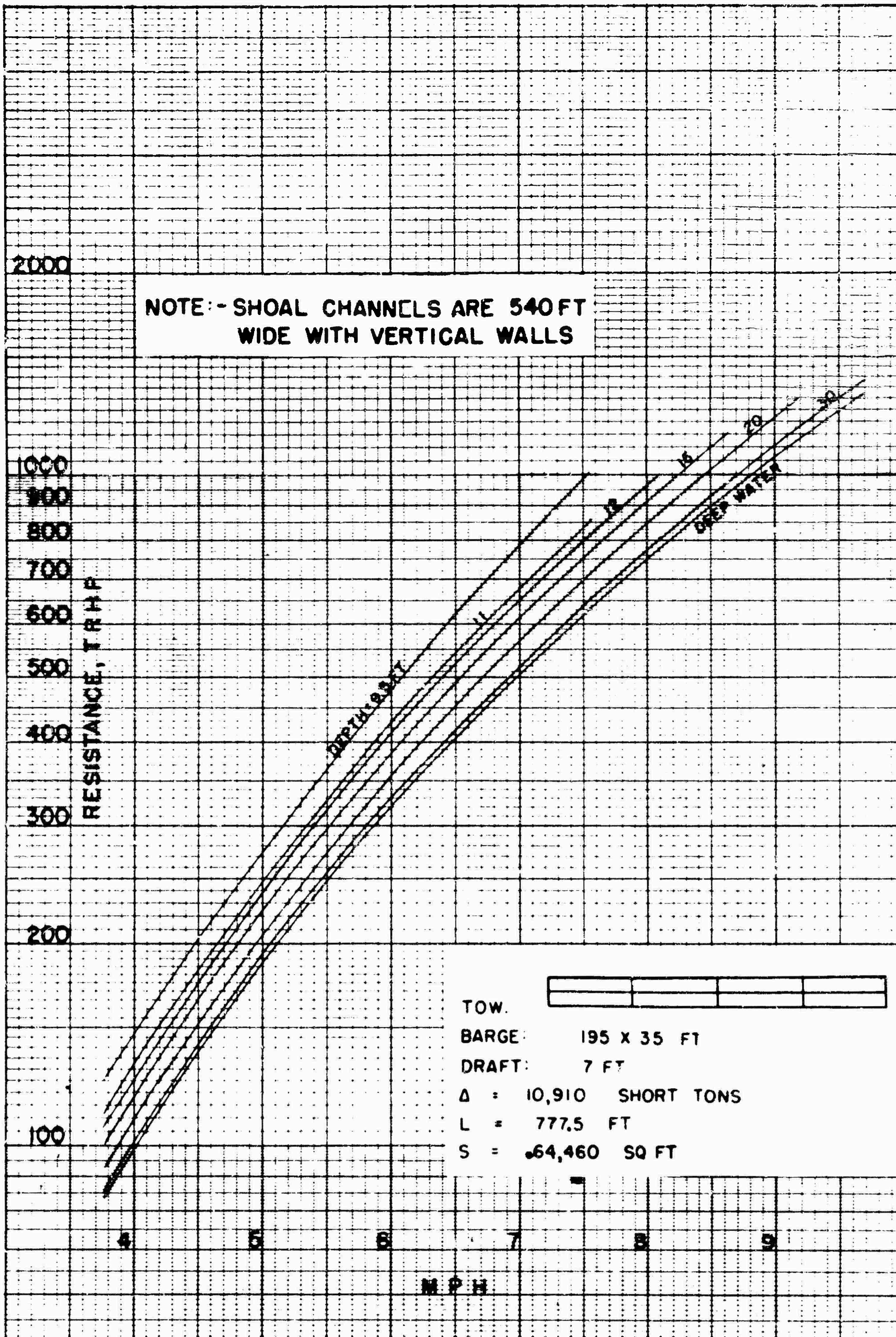
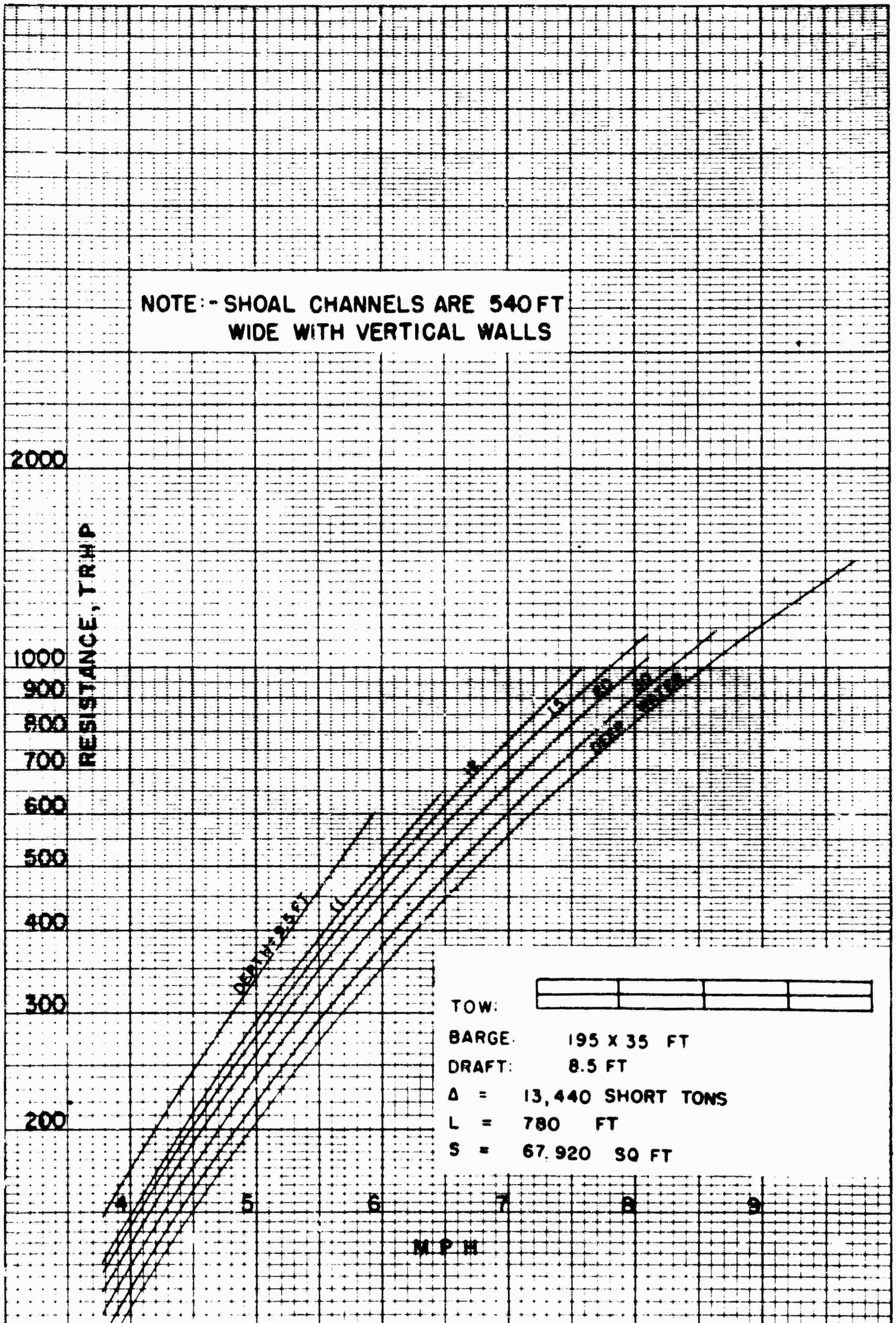

NOTE:- SHOAL CHANNELS ARE 540 FT
WIDE WITH VERTICAL WALLS
RESISTANCE, T R H P
2000
1000
900
800
700
600
500
400
300
200
100
DEPTH=9.5 FT
11
13
16
20
30
DEEP WATER
4
5
6
7
8
9
M P H
TOW.
BARGE: 195 X 35 FT
DRAFT: 7 FT
Δ = 10,910 SHORT TONS
L = 777.5 FT
S = 64,460 SQ FT

PLATE 30



NOTE:- SHOAL CHANNELS ARE 540 FT
WIDE WITH VERTICAL WALLS
RESISTANCE, TRHP
2000
1000
900
800
700
600
500
400
300
200
15
20
TOW:
BARGE 195 X 35 FT
DRAFT: 8.5 FT
Δ = 13,440 SHORT TONS
L = 780 FT
S = 67,920 SQ FT
4
5
6
7
8
9
M P H

PLATE 31

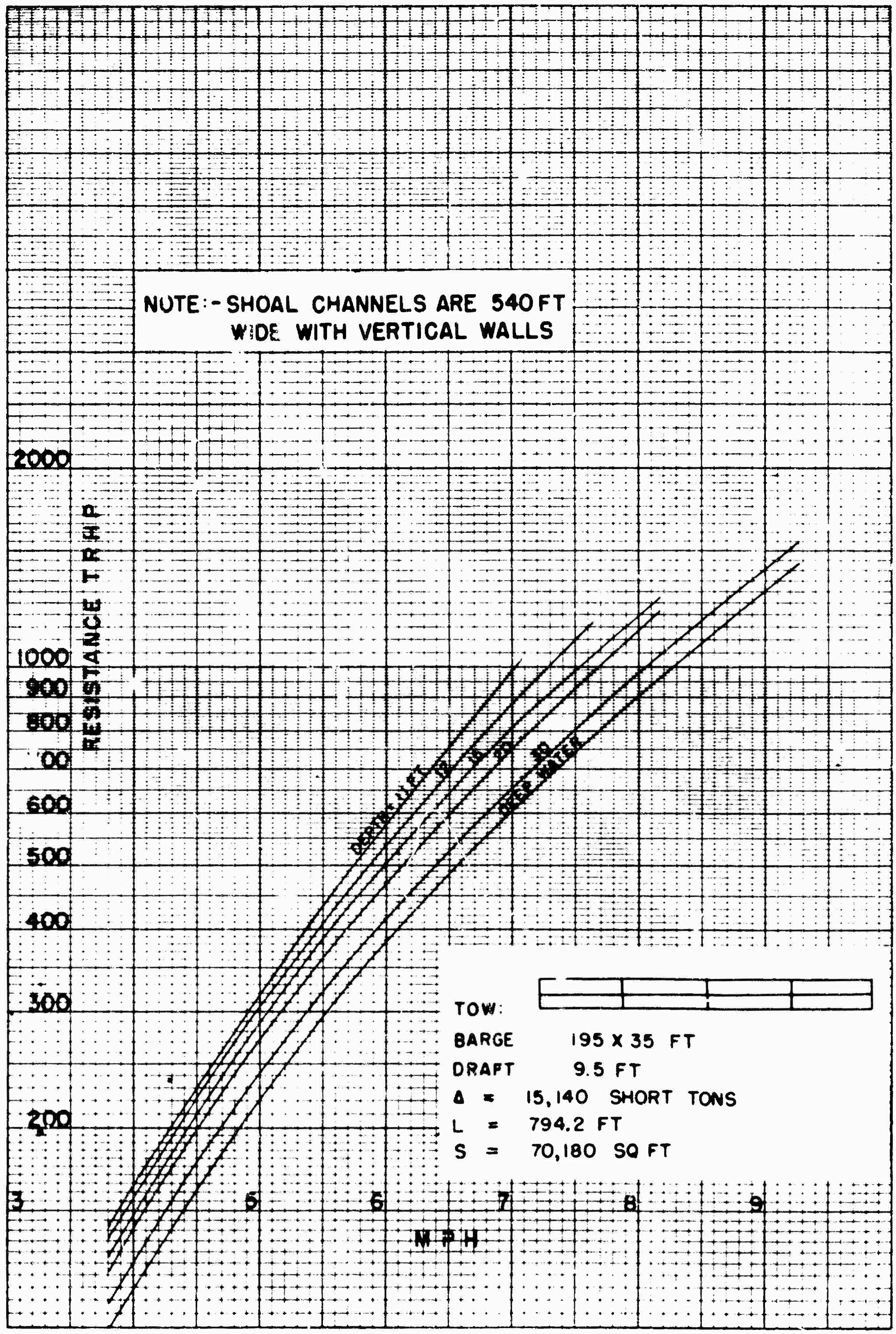
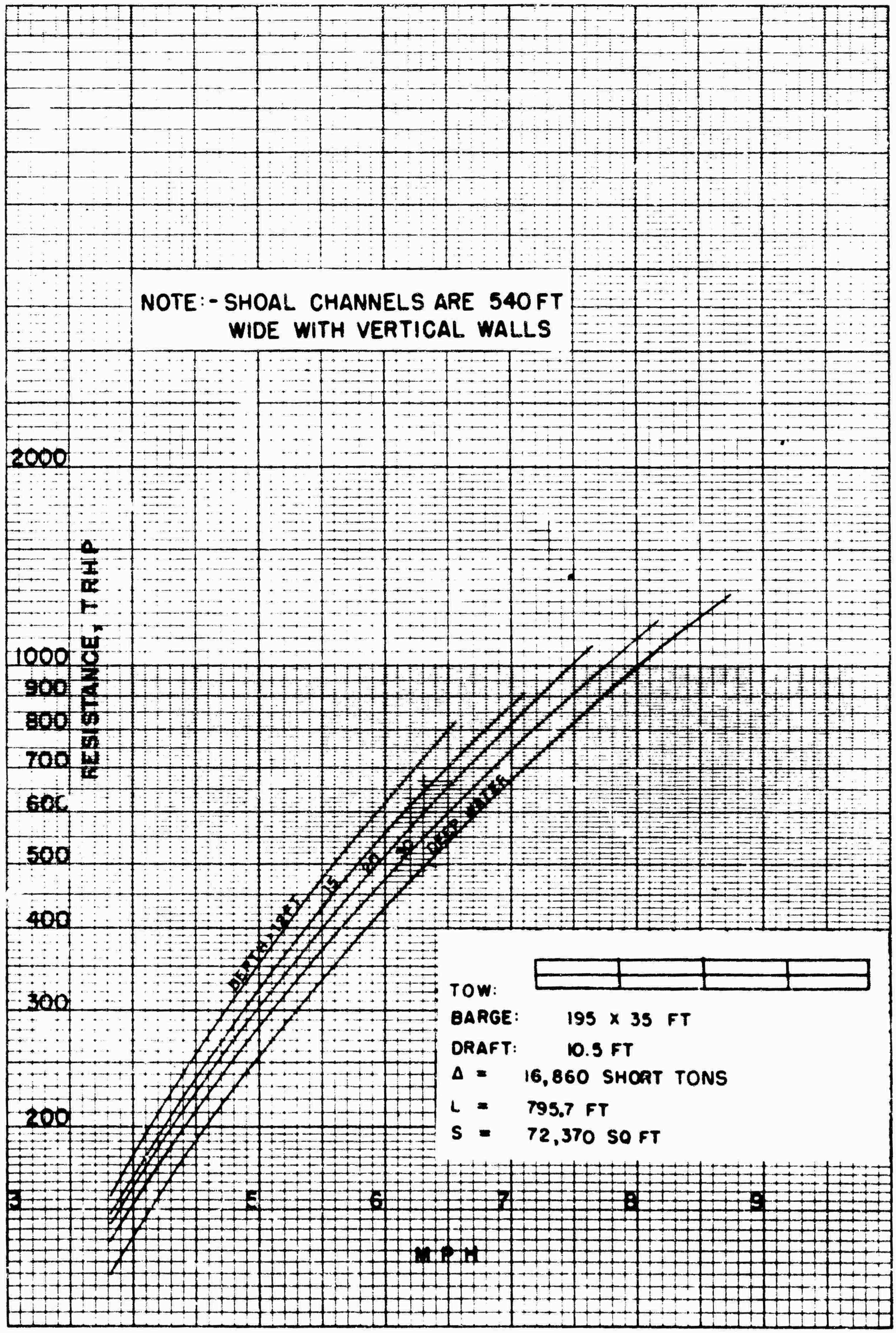
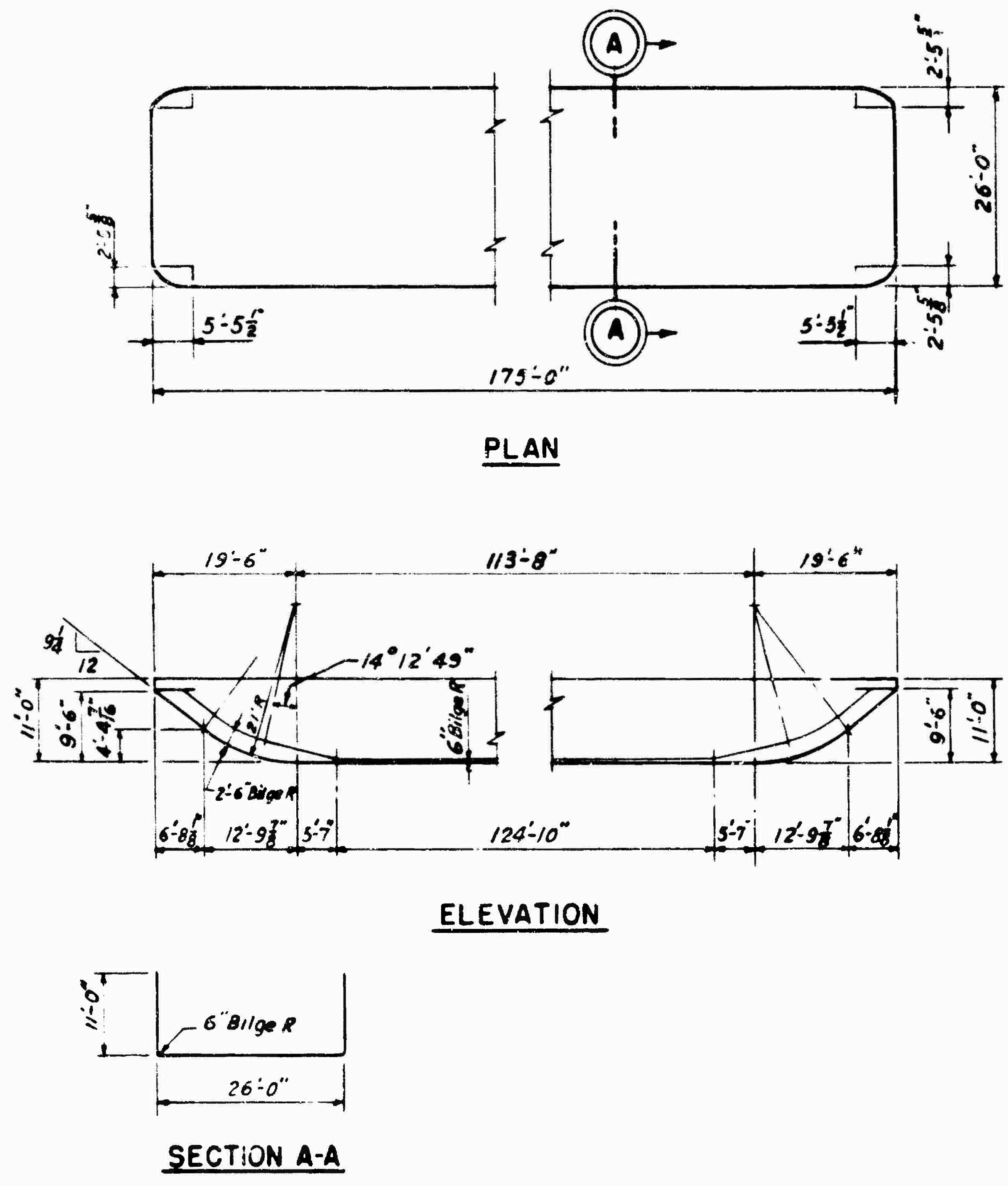

NOTE:-SHOAL CHANNELS ARE 540 FT
WIDE WITH VERTICAL WALLS
2000
1000
900
800
600
500
400
300
200
RESISTANCE T.R.H.P.
3
5
6
7
8
9
M P H
DEPTH 11 FT
13
15
20
30
DEEP WATER
TOW:
BARGE 195 X 35 FT
DRAFT 9.5 FT
Δ = 15,140 SHORT TONS
L = 794.2 FT
S = 70,180 SQ FT

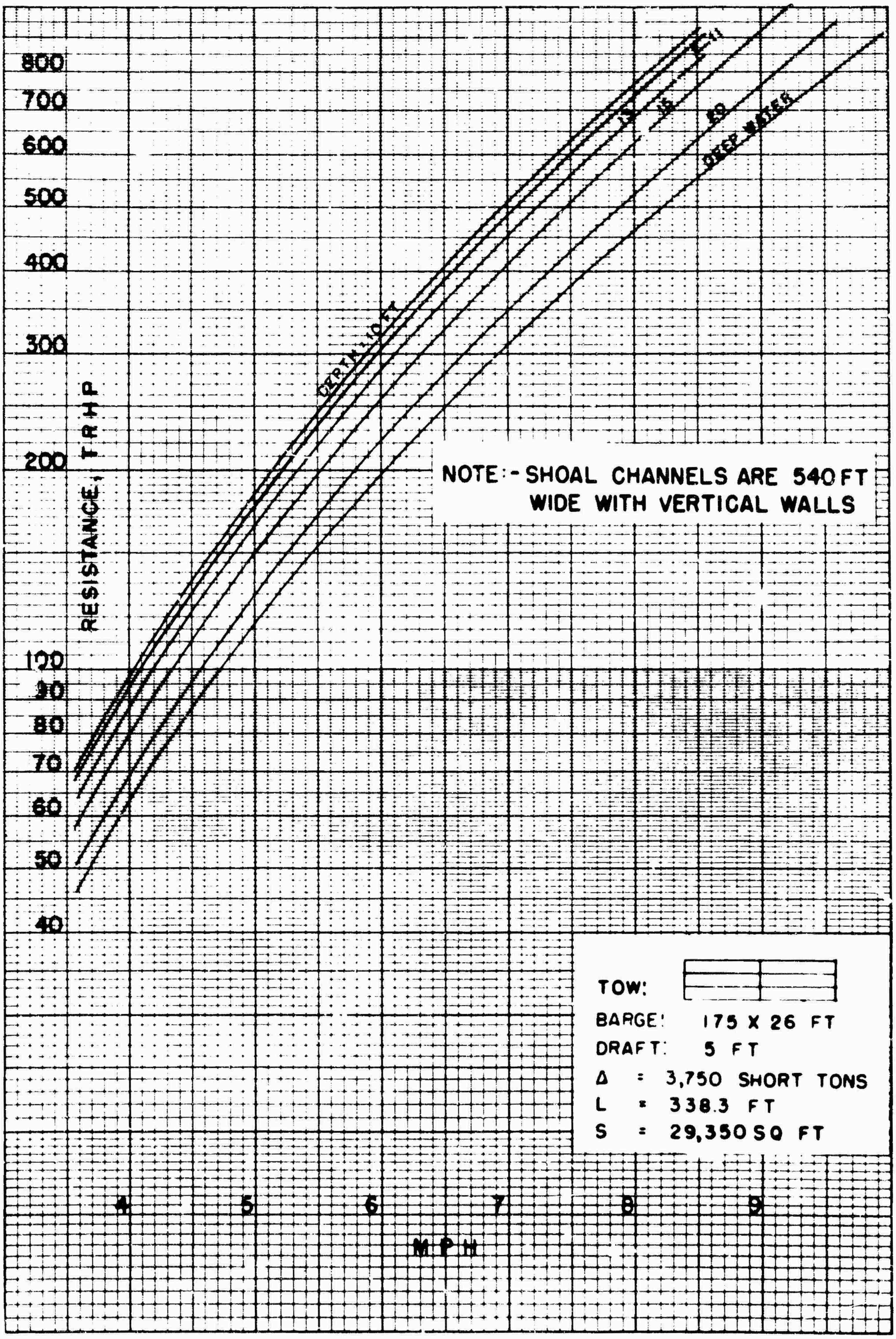
PLATE 32


NOTE:- SHOAL CHANNELS ARE 540 FT
WIDE WITH VERTICAL WALLS
RESISTANCE, TRHP
2000
1000
900
800
700
600
500
400
300
200
3
5
6
7
8
9
MPH
DEPTH, 12 FT
15
20
30
DEEP WATER
TOW:
BARGE: 195 X 35 FT
DRAFT: 10.5 FT
Δ = 16,860 SHORT TONS
L = 795.7 FT
S = 72,370 SQ FT



NOTE:
Design of coal barge
Built by American Bridge CO.,
for use by Carnegie Illinois
Steel CO.

175-FT X 26-FT BARGE
FOR TESTS ON
PLATES 35 TO 37 INCL.


800
700
600
500
400
300
200
100
90
80
70
60
50
40
RESISTANCE, TRHP
DEPTH = 10 FT
20
DEEP WATER
NOTE:- SHOAL CHANNELS ARE 540 FT WIDE WITH VERTICAL WALLS
TOW:
BARGE: 175 X 26 FT
DRAFT: 5 FT
Δ = 3,750 SHORT TONS
L = 338.3 FT
S = 29,350 SQ FT
4
5
6
7
8
9
MPH

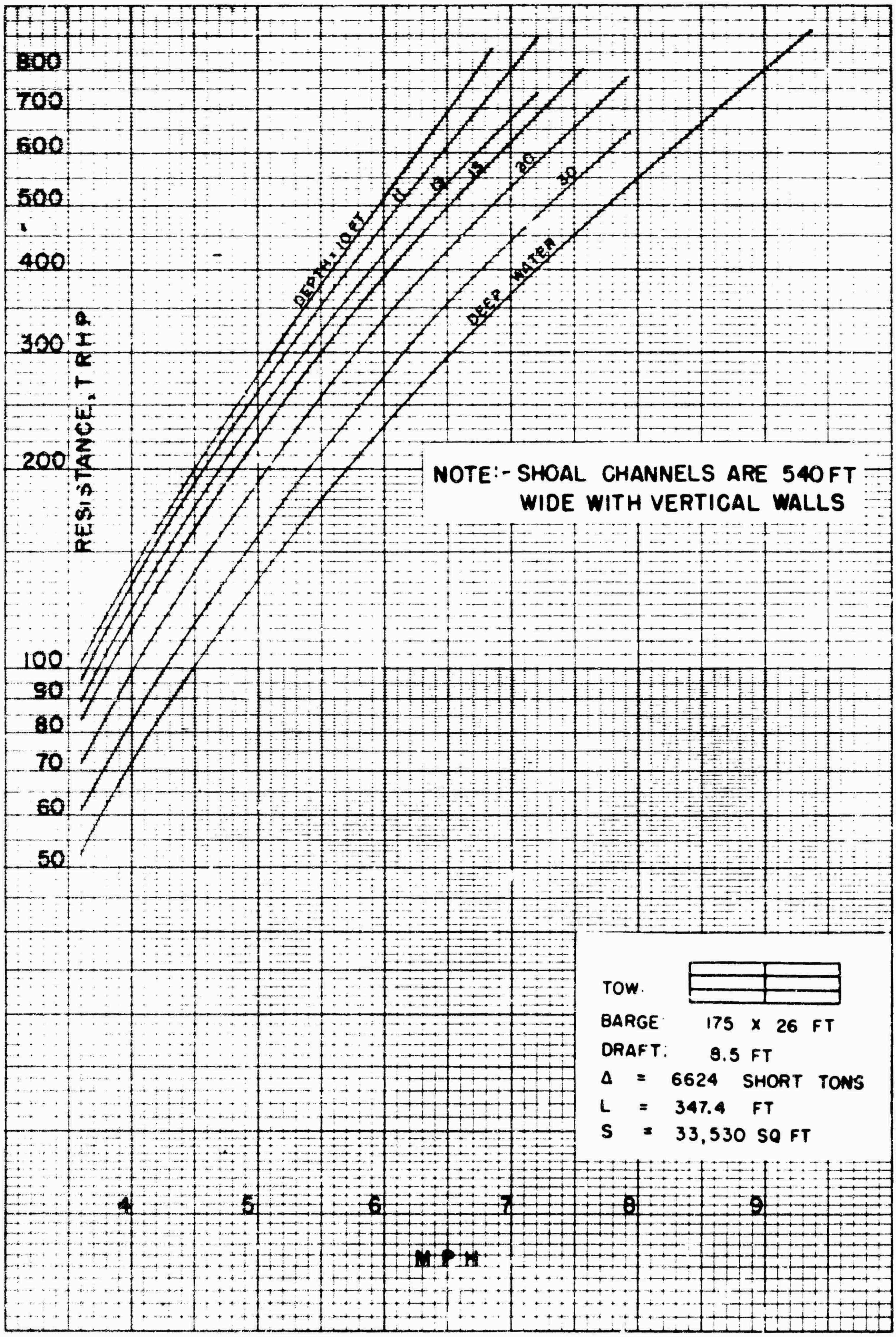
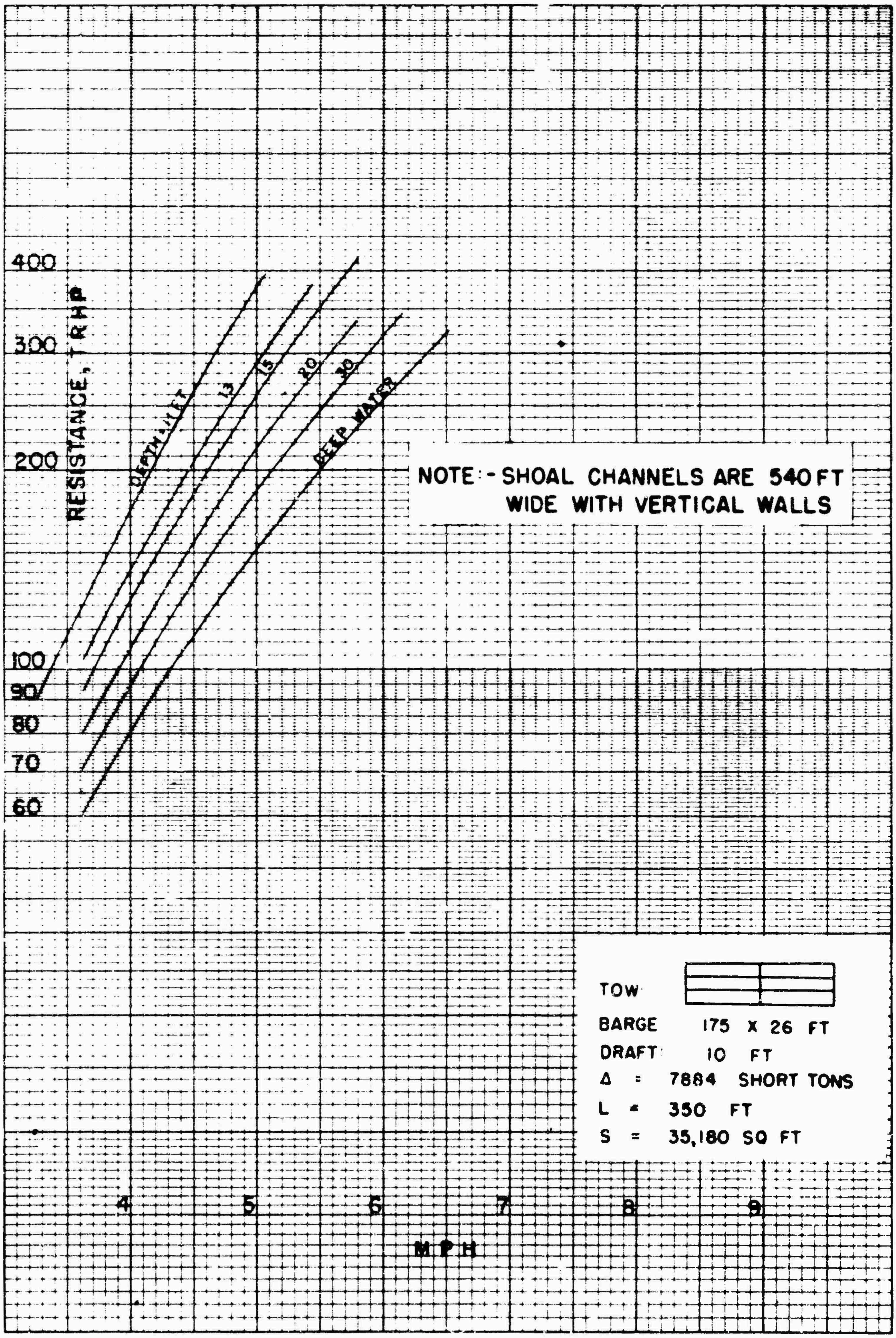
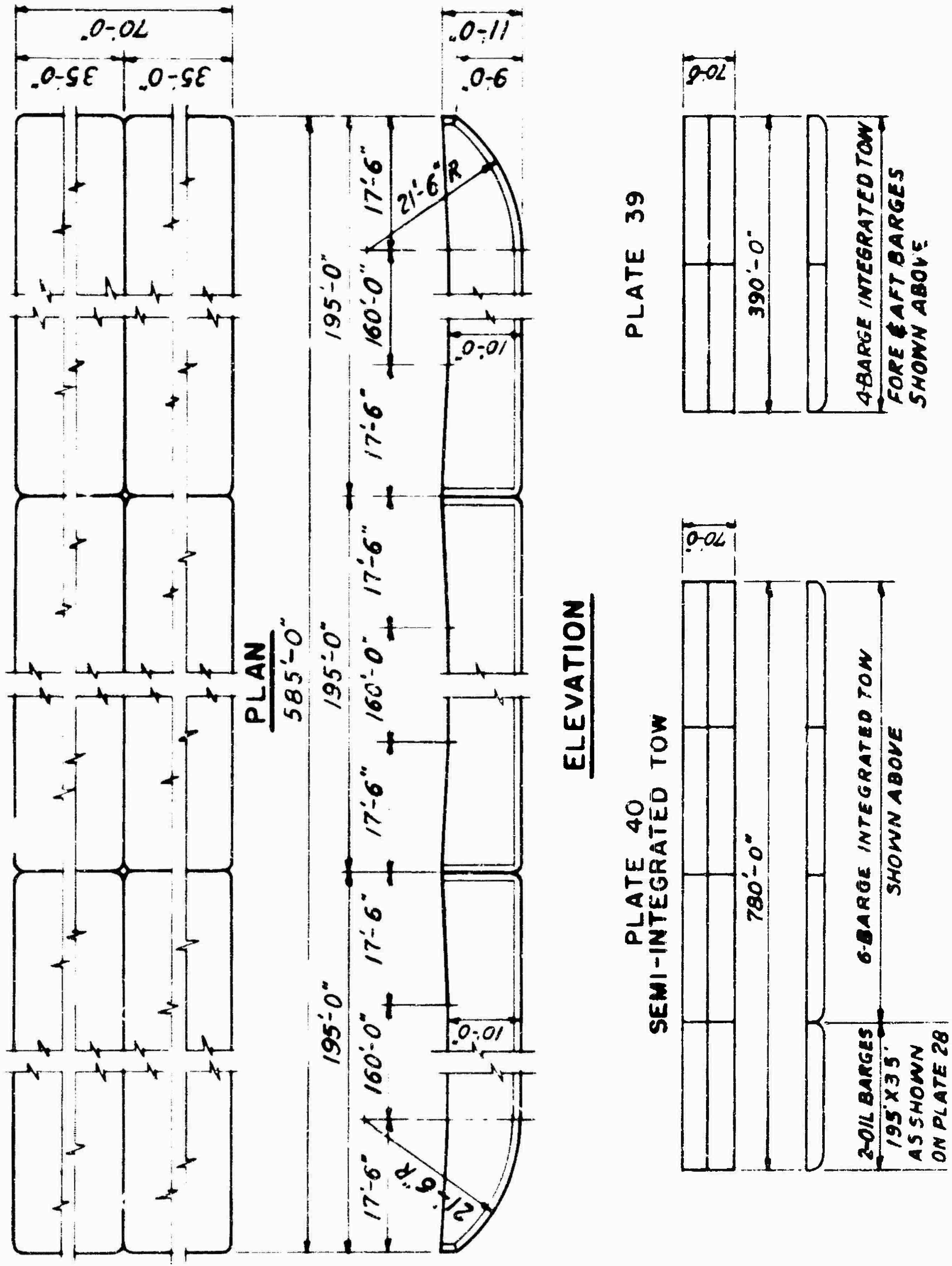

800
700
600
500
400
300
200
100
90
80
70
60
50
RESISTANCE, T R H P
DEPTH: 10 FT
11
13
15
20
30
DEEP WATER
NOTE:- SHOAL CHANNELS ARE 540 FT WIDE WITH VERTICAL WALLS
TOW
BARGE 175 X 26 FT
DRAFT: 8.5 FT
Δ = 6624 SHORT TONS
L = 347.4 FT
S = 33,530 SQ FT
4
5
6
7
8
9
M P H

PLATE 36

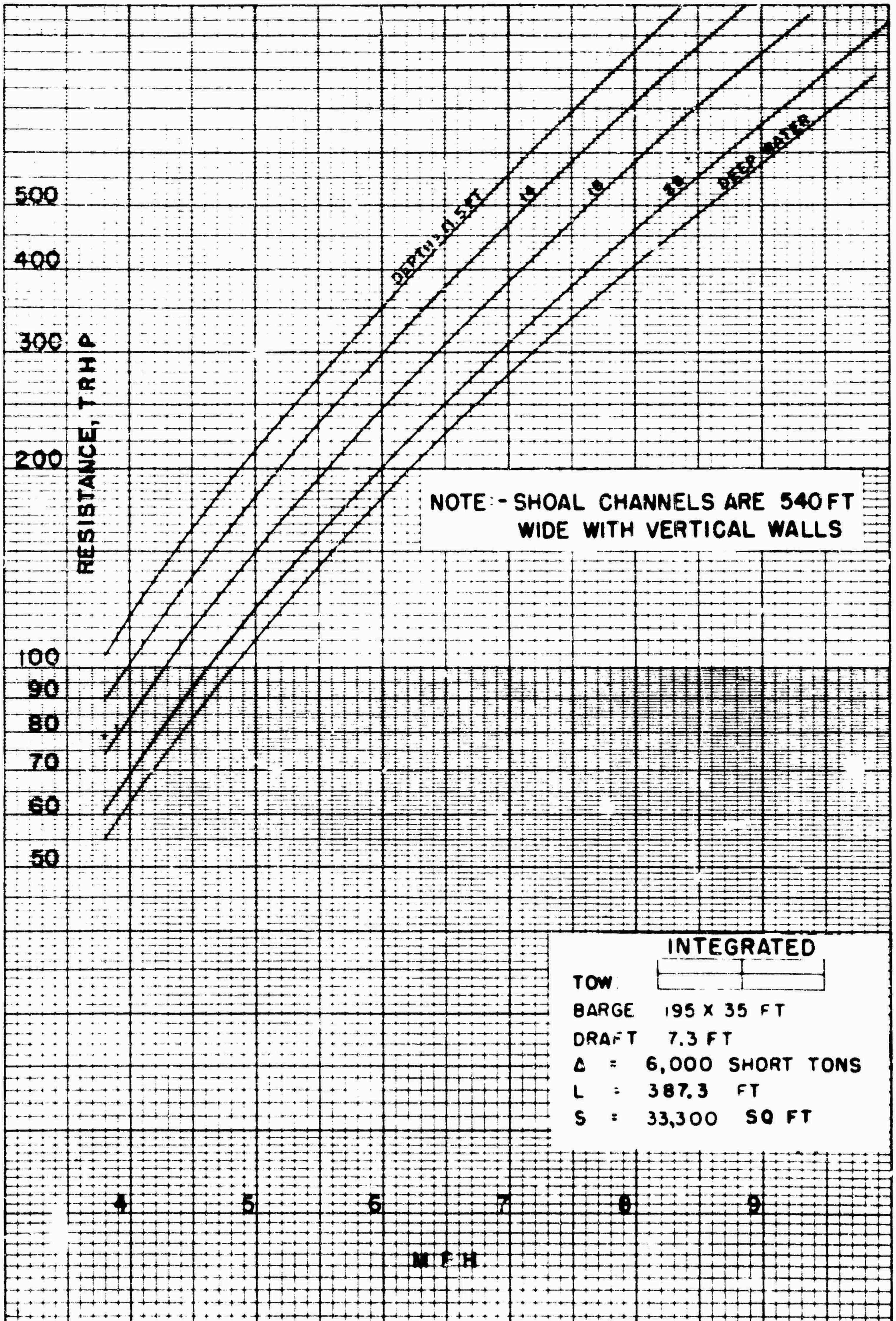


RESISTANCE, TRHP
400
300
200
100
90
80
70
60
13
15
20
30
DEEP WATER
NOTE:- SHOAL CHANNELS ARE 540 FT WIDE WITH VERTICAL WALLS
TOW
BARGE 175 X 26 FT
DRAFT 10 FT
Δ = 7884 SHORT TONS
L = 350 FT
S = 35,180 SQ FT
4
5
6
7
8
9
M P H



NOTE:
6 Gasoline barges of integrated tow follow design by Socony-Vacuum Oil CO.

4-BARGE INTEGRATED TOW
8-BARGE SEMI-INTEGRATED TOW
FOR TESTS ON
PLATES 39 & 40


RESISTANCE, TRHP
500
400
300
200
100
90
80
70
60
50
DEPTH=11.5 FT
14
18
28
DEEP WATER
NOTE:- SHOAL CHANNELS ARE 540 FT WIDE WITH VERTICAL WALLS
INTEGRATED
TOW
BARGE 195 X 35 FT
DRAFT 7.3 FT
Δ = 6,000 SHORT TONS
L = 387.3 FT
S = 33,300 SQ FT
4
5
6
7
8
9
MPH

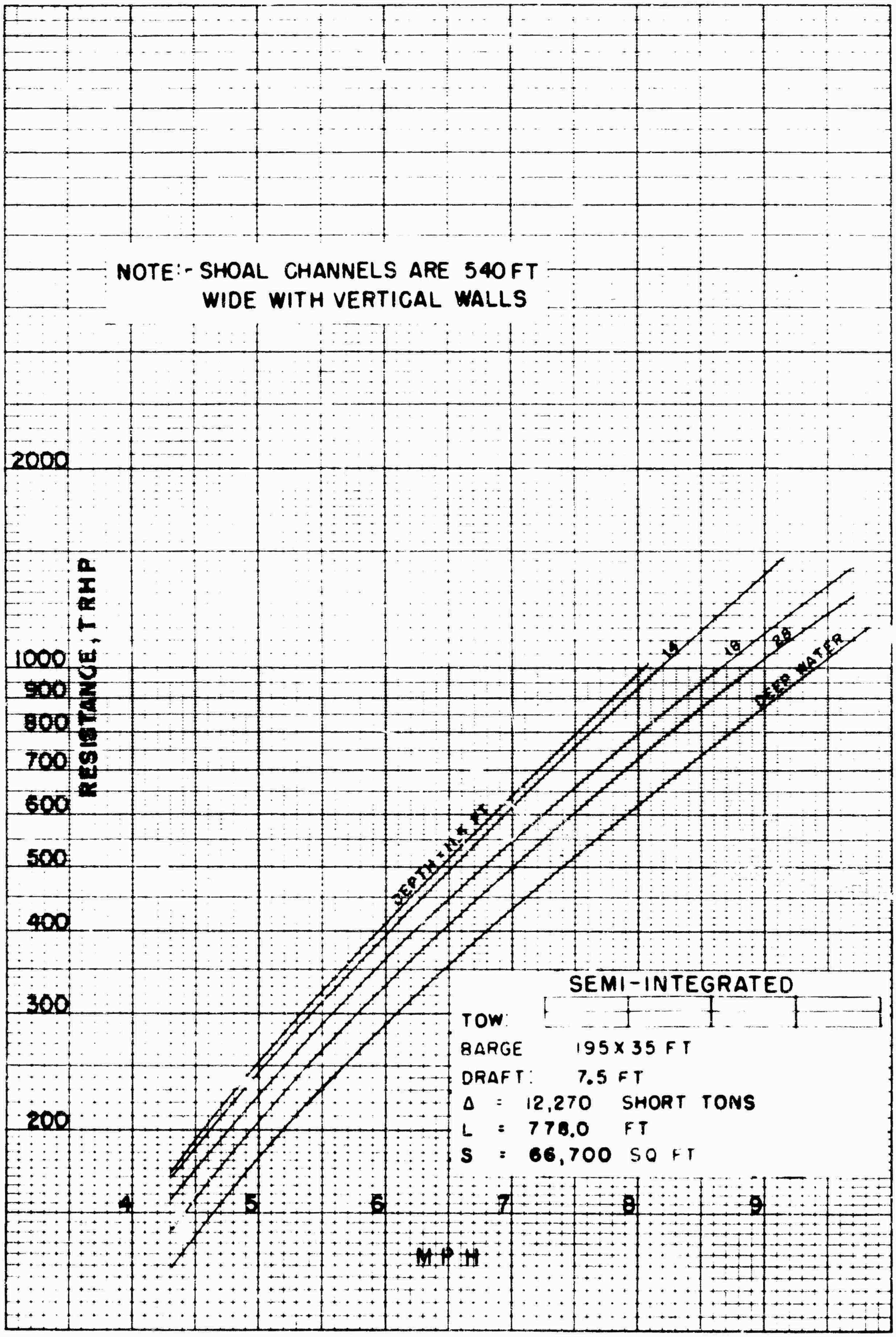
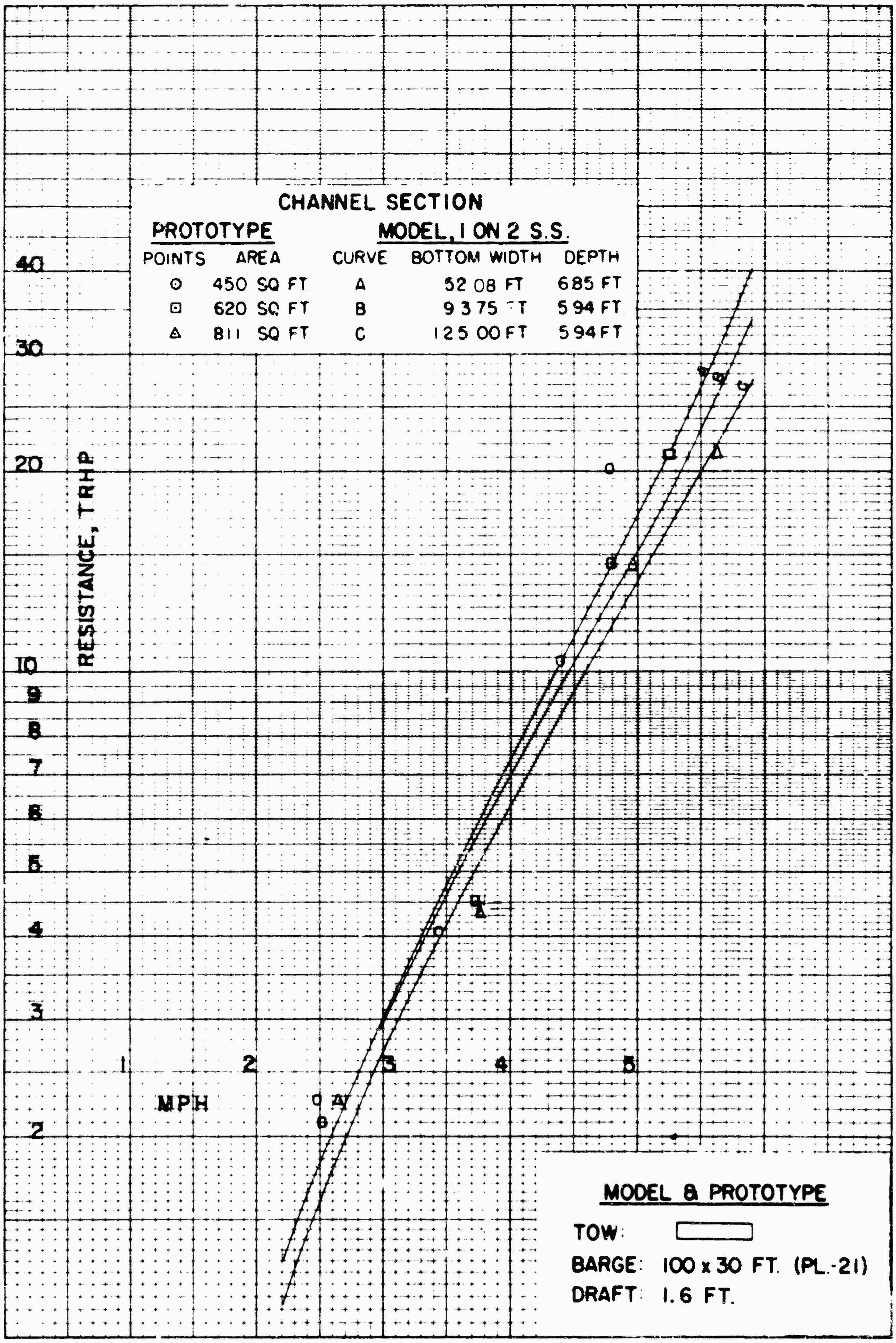

NOTE:- SHOAL CHANNELS ARE 540 FT
WIDE WITH VERTICAL WALLS
RESISTANCE, T RHP
2000
1000
900
800
700
600
500
400
300
200
DEPTH = 14 FT
16
20
DEEP WATER
SEMI-INTEGRATED
TOW:
BARGE 195 X 35 FT
DRAFT: 7.5 FT
Δ = 12,270 SHORT TONS
L = 778.0 FT
S = 66,700 SQ FT
4
5
6
7
8
9
MPH

PLATE 40



CHANNEL SECTION
PROTOTYPE
MODEL, 1 ON 2 S.S.
POINTS AREA CURVE BOTTOM WIDTH DEPTH
○ 450 SQ FT A 52.08 FT 6.85 FT
□ 620 SQ FT B 93.75 FT 5.94 FT
△ 811 SQ FT C 125.00 FT 5.94 FT
RESISTANCE, TRHP
MPH
MODEL & PROTOTYPE
TOW:
BARGE: 100 x 30 FT. (PL.-21)
DRAFT: 1.6 FT.

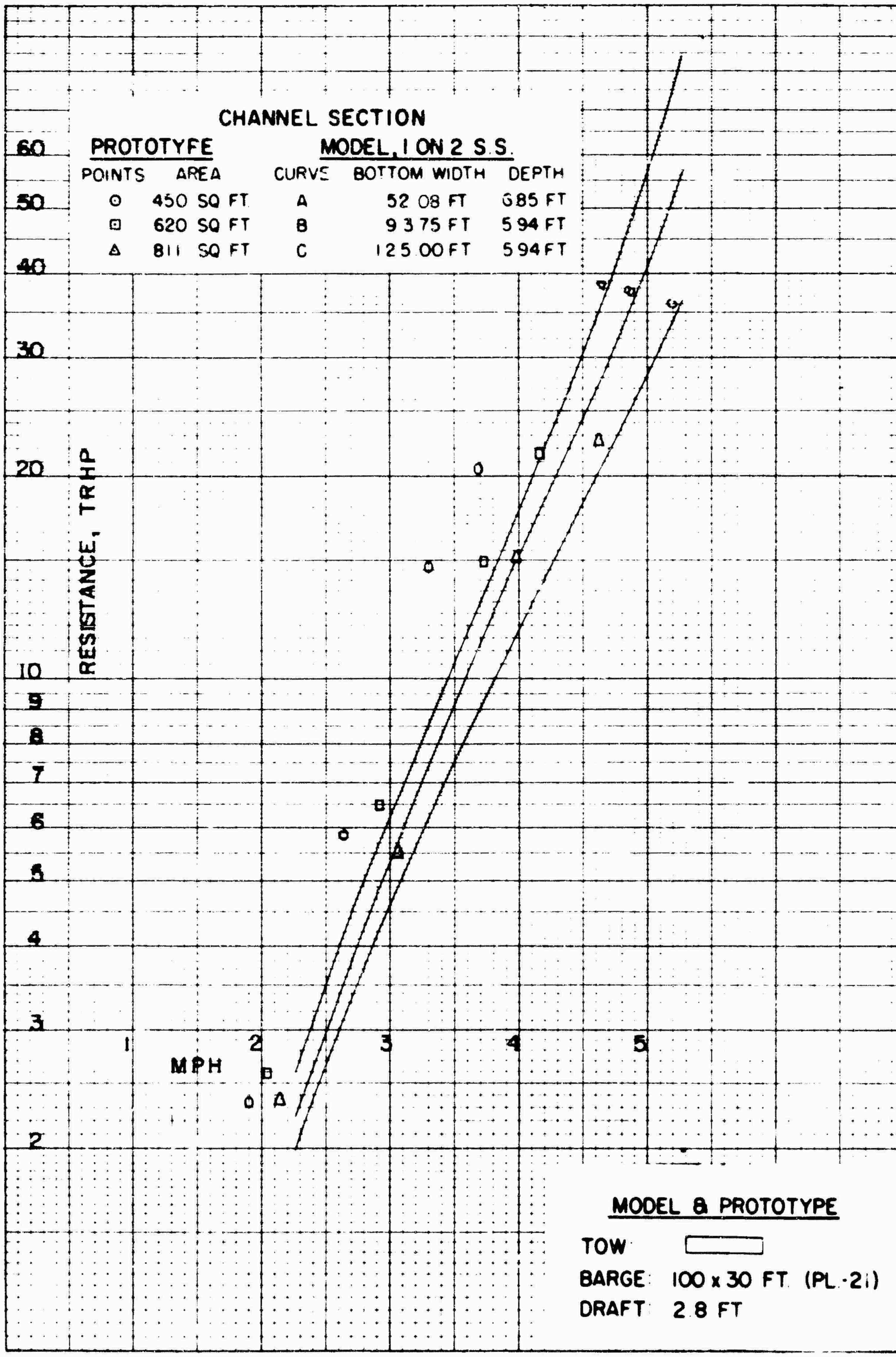

CHANNEL SECTION
PROTOTYPE
MODEL, 1 ON 2 S.S.
POINTS AREA CURVE BOTTOM WIDTH DEPTH
○ 450 SQ FT A 52.08 FT 6.85 FT
□ 620 SQ FT B 93.75 FT 5.94 FT
△ 811 SQ FT C 125.00 FT 5.94 FT
RESISTANCE, TRHP
MPH
MODEL & PROTOTYPE
TOW
BARGE 100 x 30 FT (PL-21)
DRAFT 2.8 FT

PLATE 42

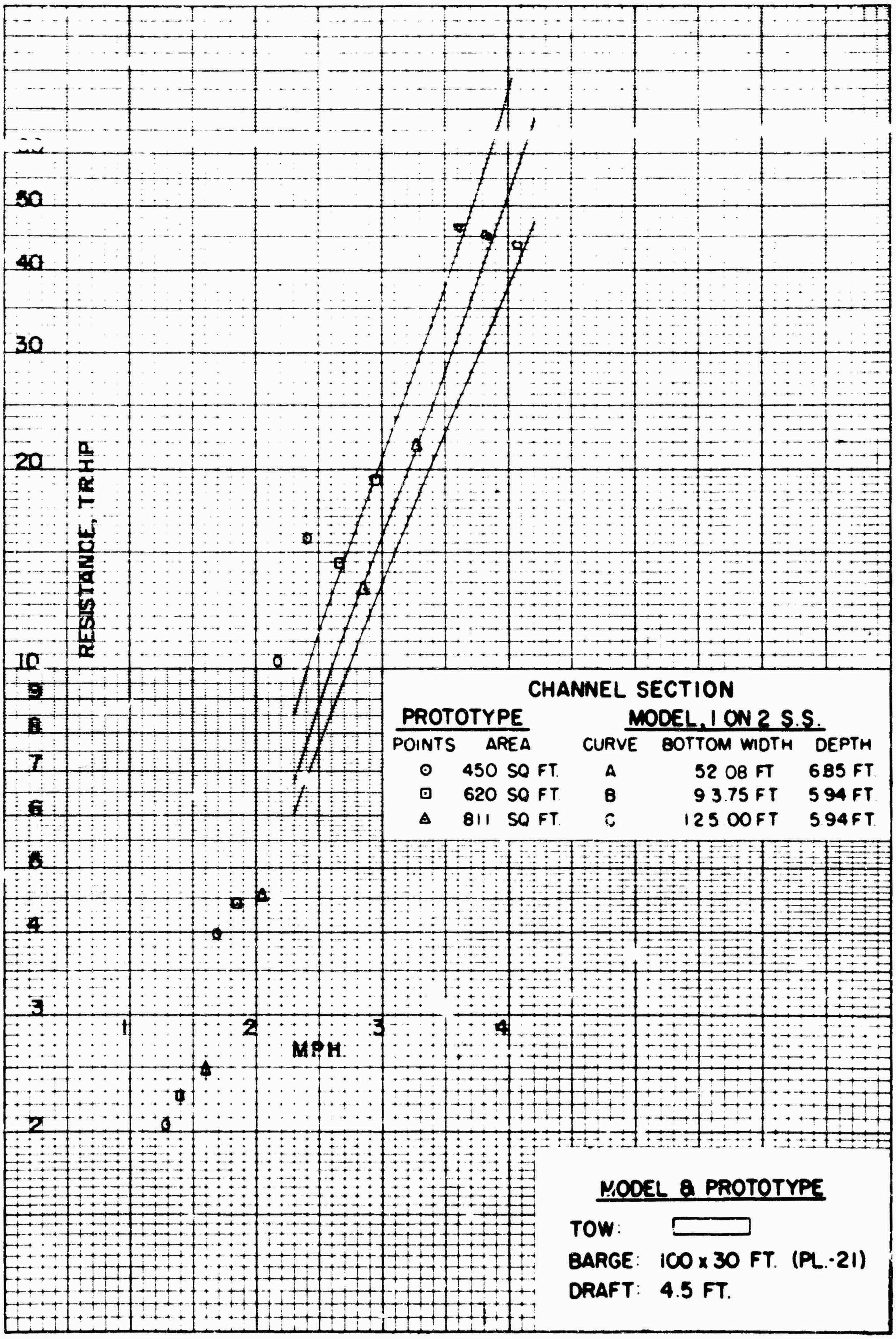
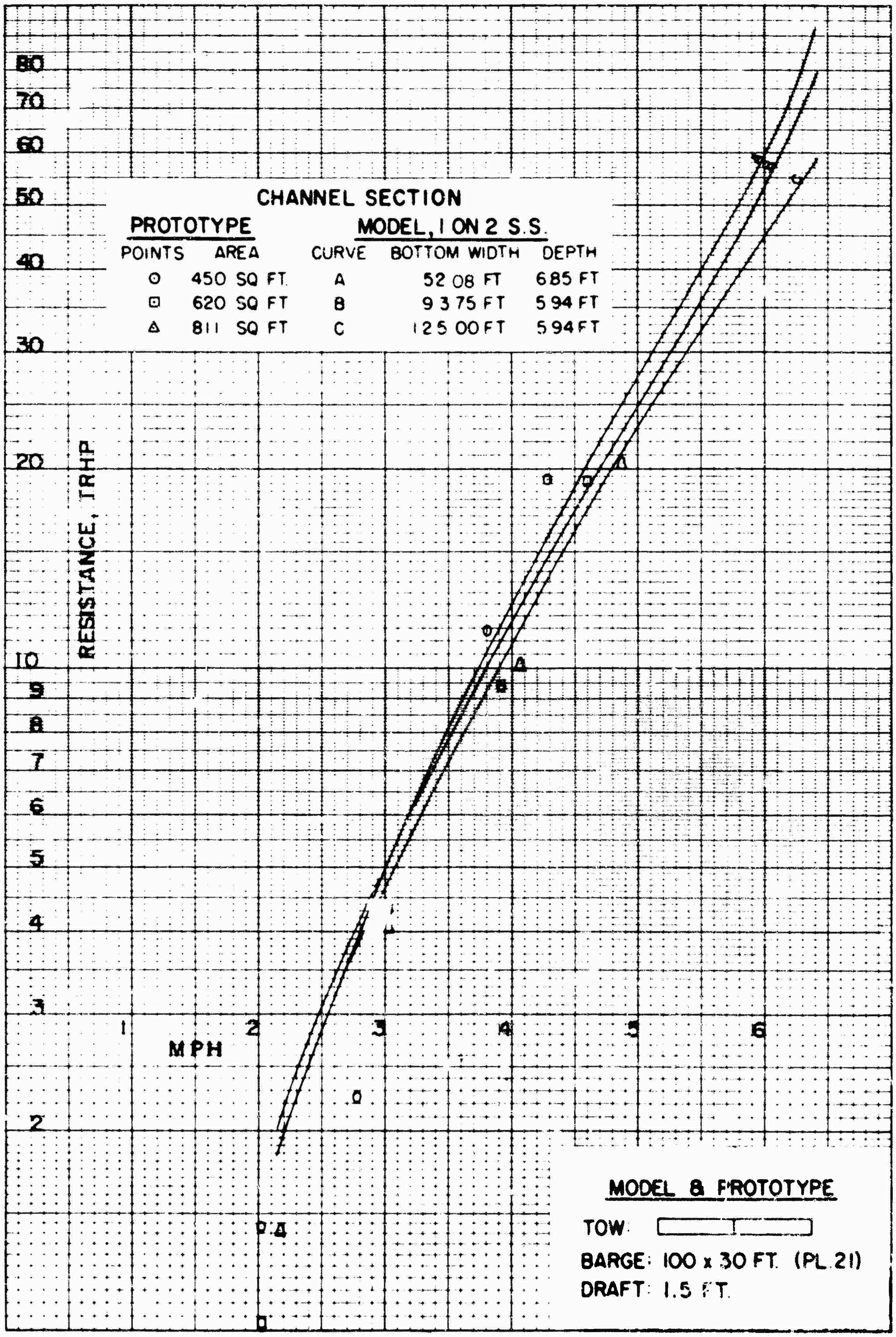
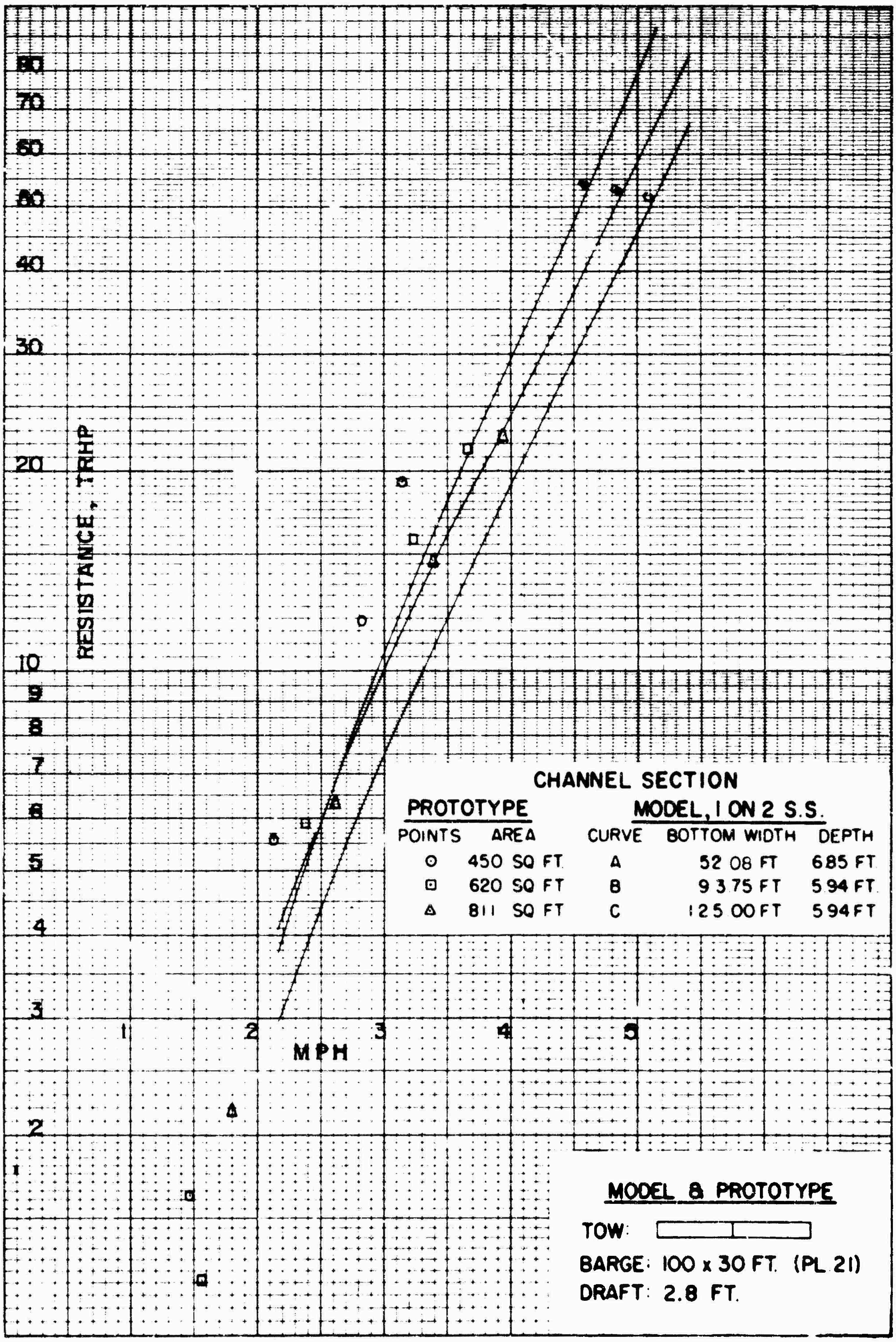

50
40
30
20
10
9
8
7
6
5
4
3
2
RESISTANCE, TR.H.P.
1
2
3
4
MPH
CHANNEL SECTION
PROTOTYPE
MODEL, 1 ON 2 S.S.
POINTS AREA CURVE BOTTOM WIDTH DEPTH
⊙ 450 SQ FT. A 52.08 FT 6.85 FT
⊡ 620 SQ FT. B 93.75 FT 5.94 FT
△ 811 SQ FT. C 125.00 FT 5.94 FT
MODEL & PROTOTYPE
TOW:
BARGE: 100 x 30 FT. (PL.-21)
DRAFT: 4.5 FT.

PLATE 43



CHANNEL SECTION
PROTOTYPE
MODEL, 1 ON 2 S.S.
POINTS AREA
CURVE BOTTOM WIDTH DEPTH
○ 450 SQ FT A 52.08 FT 6.85 FT
□ 620 SQ FT B 93.75 FT 5.94 FT
△ 811 SQ FT C 125.00 FT 5.94 FT
RESISTANCE, TRHP
MPH
MODEL & PROTOTYPE
TOW:
BARGE: 100 x 30 FT. (PL. 21)
DRAFT: 1.5 FT.

PLATE 44



RESISTANCE, TRHP
MPH
CHANNEL SECTION
PROTOTYPE
MODEL, 1 ON 2 S.S.
POINTS AREA
○ 450 SQ FT
□ 620 SQ FT
△ 811 SQ FT
CURVE BOTTOM WIDTH DEPTH
A 52.08 FT 6.85 FT
B 93.75 FT 5.94 FT
C 125.00 FT 5.94 FT
MODEL & PROTOTYPE
TOW:
BARGE: 100 x 30 FT. (PL 21)
DRAFT: 2.8 FT.

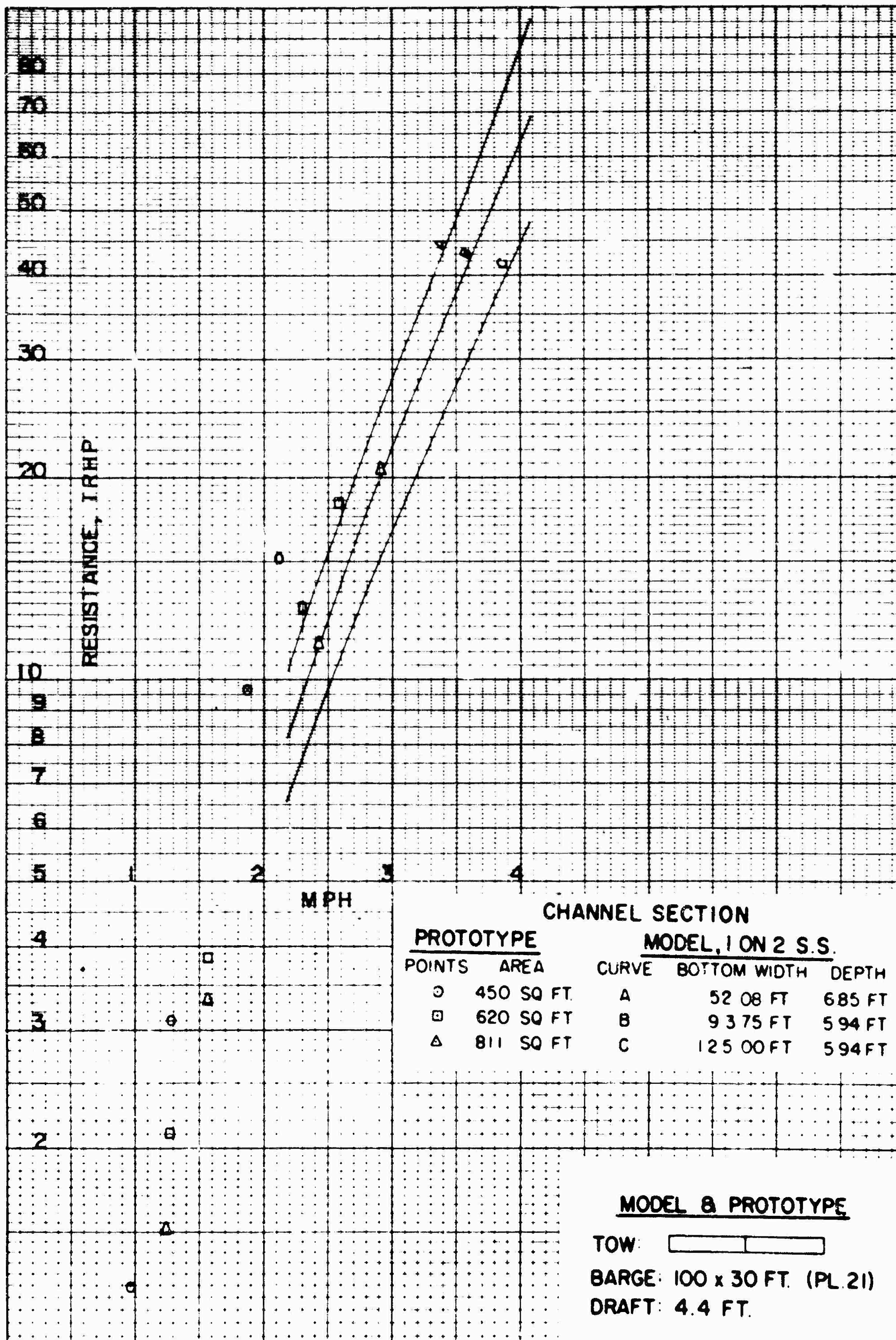
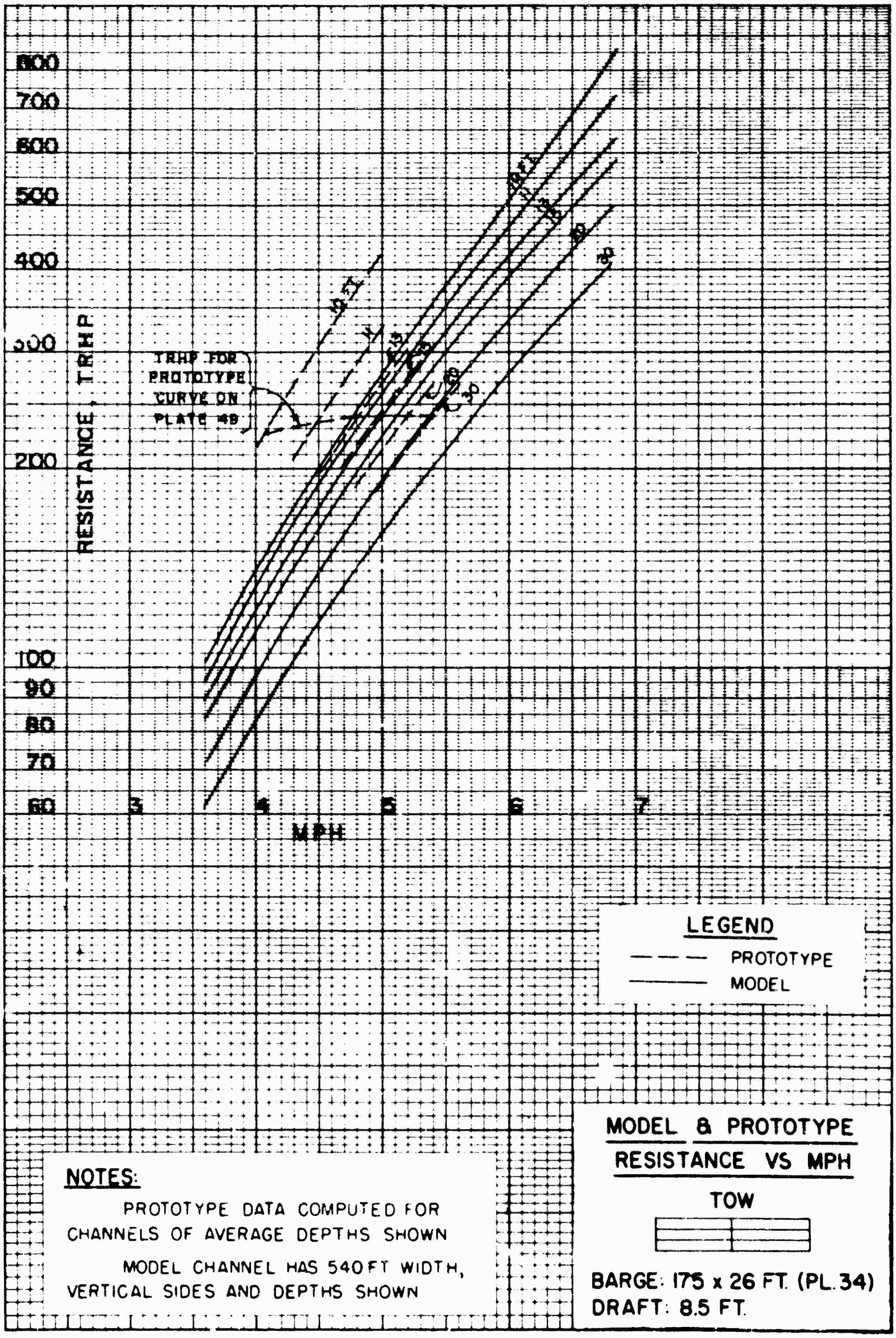

RESISTANCE, TRHP
MPH
CHANNEL SECTION
PROTOTYPE
POINTS AREA
○ 450 SQ FT
□ 620 SQ FT
△ 811 SQ FT
MODEL, 1 ON 2 S.S.
CURVE BOTTOM WIDTH DEPTH
A 52 08 FT 685 FT
B 93 75 FT 594 FT
C 125 00 FT 594 FT
MODEL & PROTOTYPE
TOW
BARGE: 100 x 30 FT. (PL.21)
DRAFT: 4.4 FT.

PLATE 46



NOTES:

PROTOTYPE DATA COMPUTED FOR CHANNELS OF AVERAGE DEPTHS SHOWN

MODEL CHANNEL HAS 540 FT WIDTH, VERTICAL SIDES AND DEPTHS SHOWN

MODEL & PROTOTYPE RESISTANCE VS MPH

TOW

BARGE: 175 x 26 FT. (PL. 34)
DRAFT: 8.5 FT.

PLATE 47

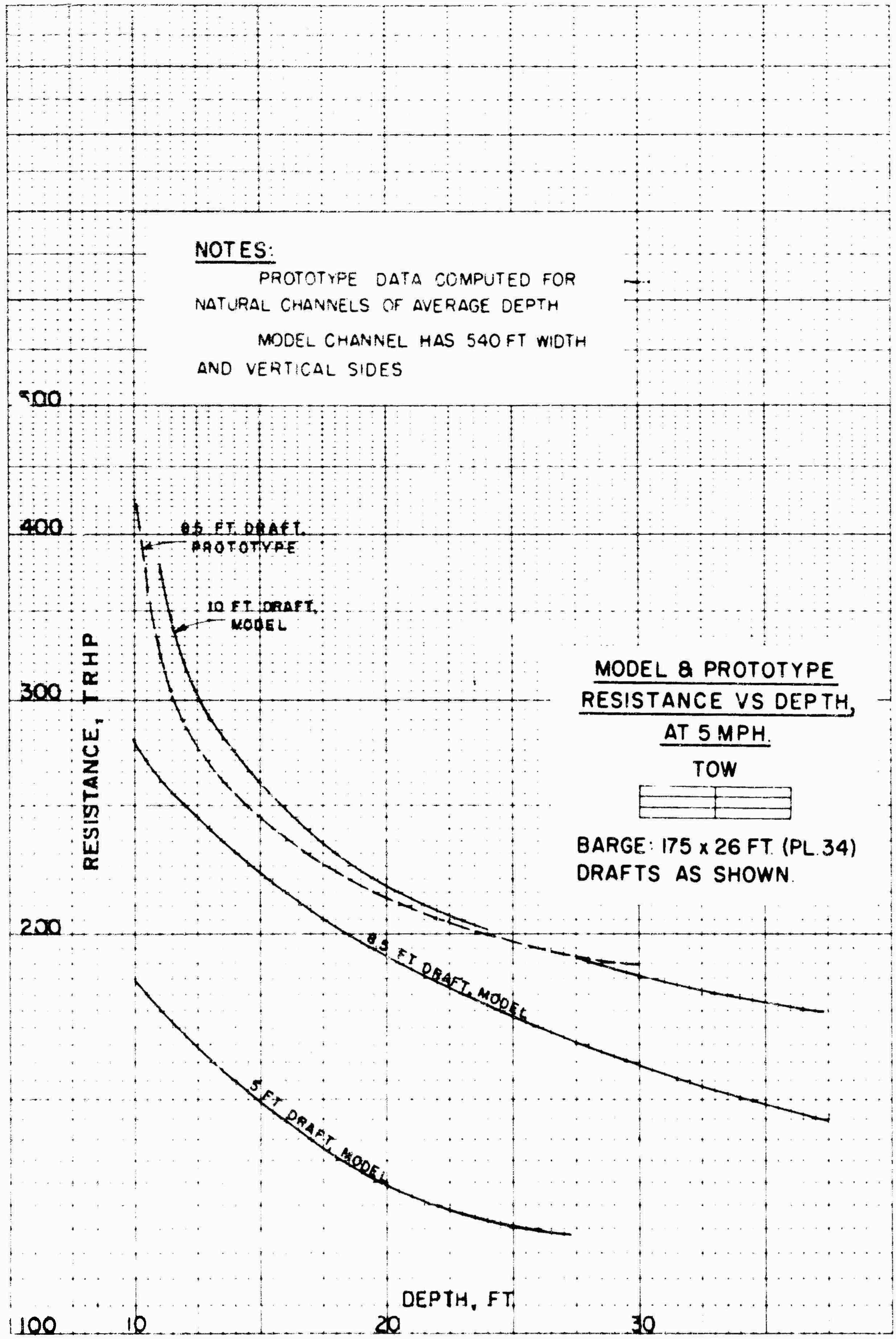
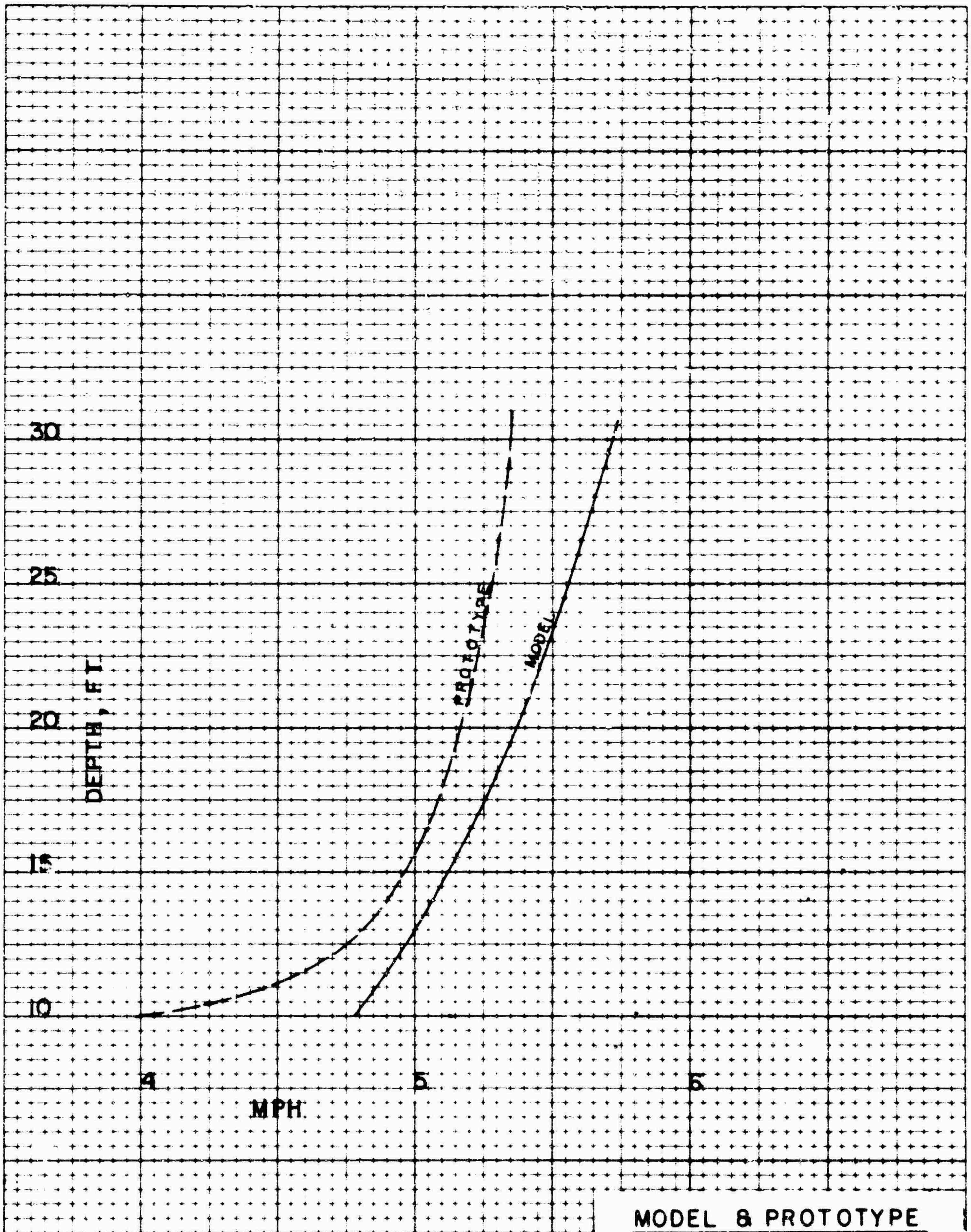

NOTES:
PROTOTYPE DATA COMPUTED FOR NATURAL CHANNELS OF AVERAGE DEPTH
MODEL CHANNEL HAS 540 FT WIDTH AND VERTICAL SIDES
MODEL & PROTOTYPE RESISTANCE VS DEPTH, AT 5 MPH.
TOW
BARGE: 175 x 26 FT. (PL.34)
DRAFTS AS SHOWN.
8.5 FT. DRAFT, PROTOTYPE
10 FT. DRAFT, MODEL
8.5 FT DRAFT, MODEL
5 FT DRAFT, MODEL
RESISTANCE, TRHP
DEPTH, FT
500
400
300
200
100
10
20
30

PLATE 48



NOTES:

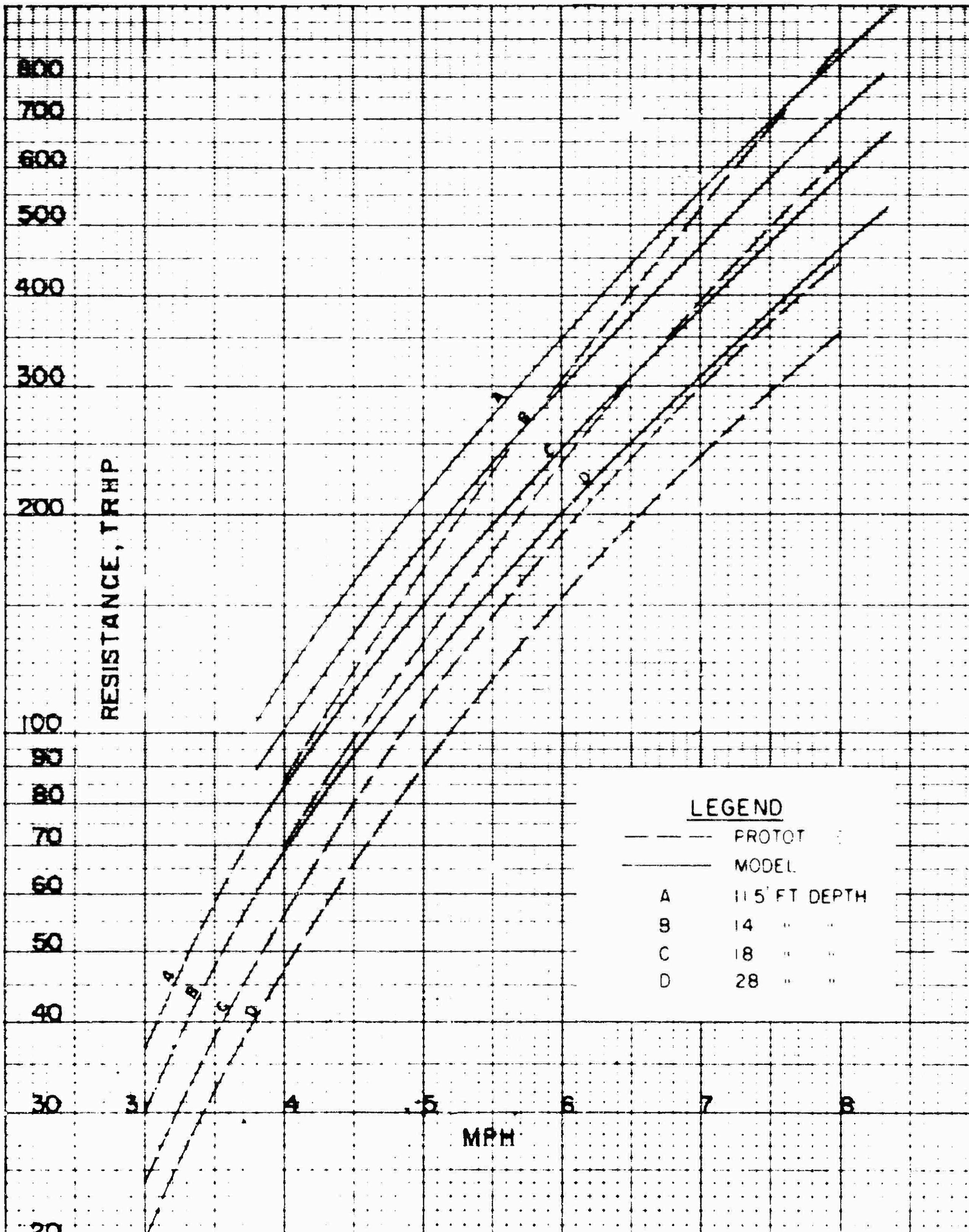
PROTOTYPE CURVE COMPUTED FOR VIRTUALLY CONSTANT TRHP. (PL 47)

MODEL CURVE COMPUTED FOR 240 TRHP

MODEL & PROTOTYPE
DEPTH VS MPH

TOW

BARGE: 175 x 26 FT. (PL. 34)
DRAFT: 8.5 FT.



NOTES.

PROTOTYPE DATA COMPUTED FOR CHANNELS OF AVERAGE DEPTHS SHOWN

MODEL CHANNEL HAS 540 FT WIDTH, VERTICAL SIDES AND DEPTHS SHOWN

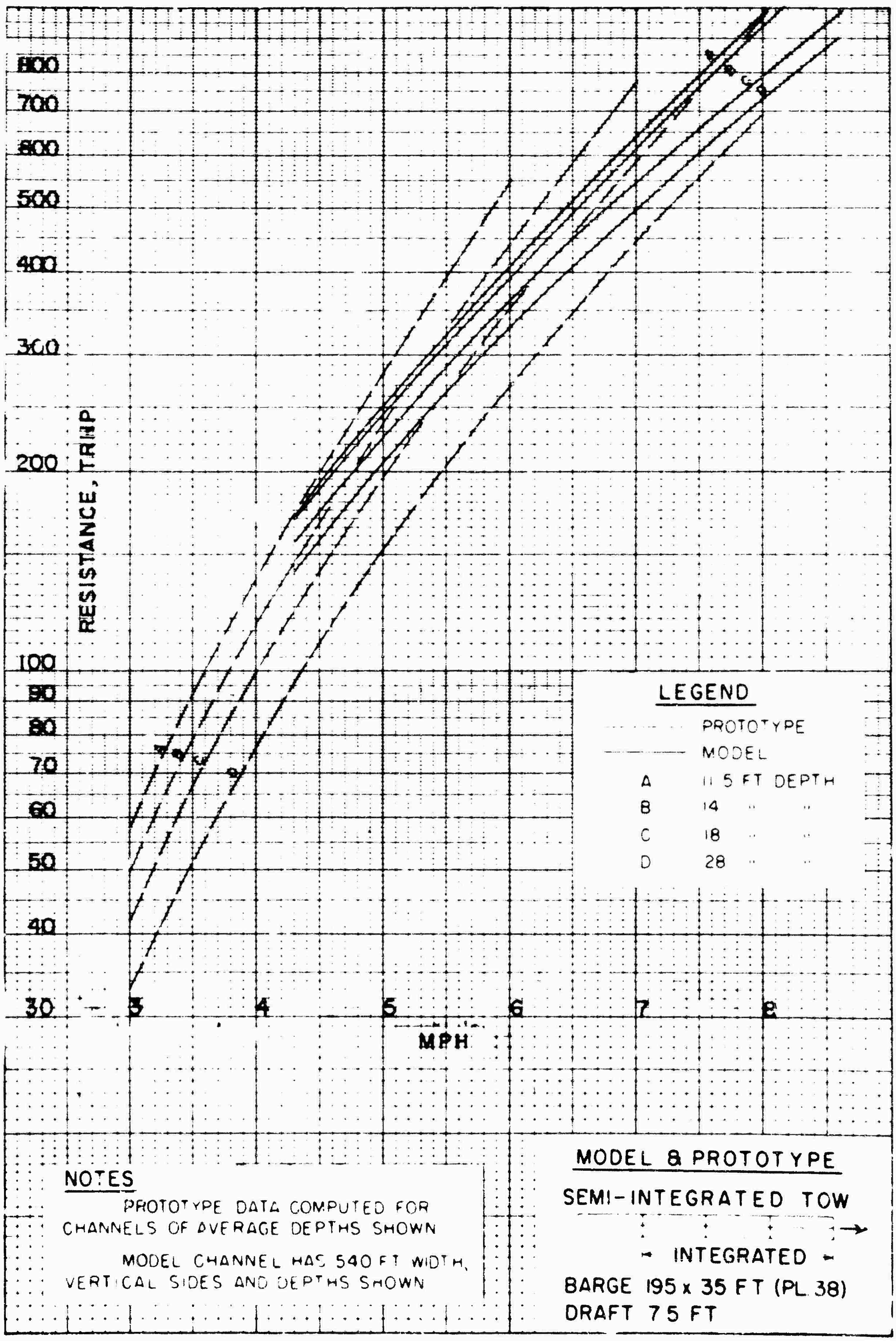
MODEL & PROTOTYPE

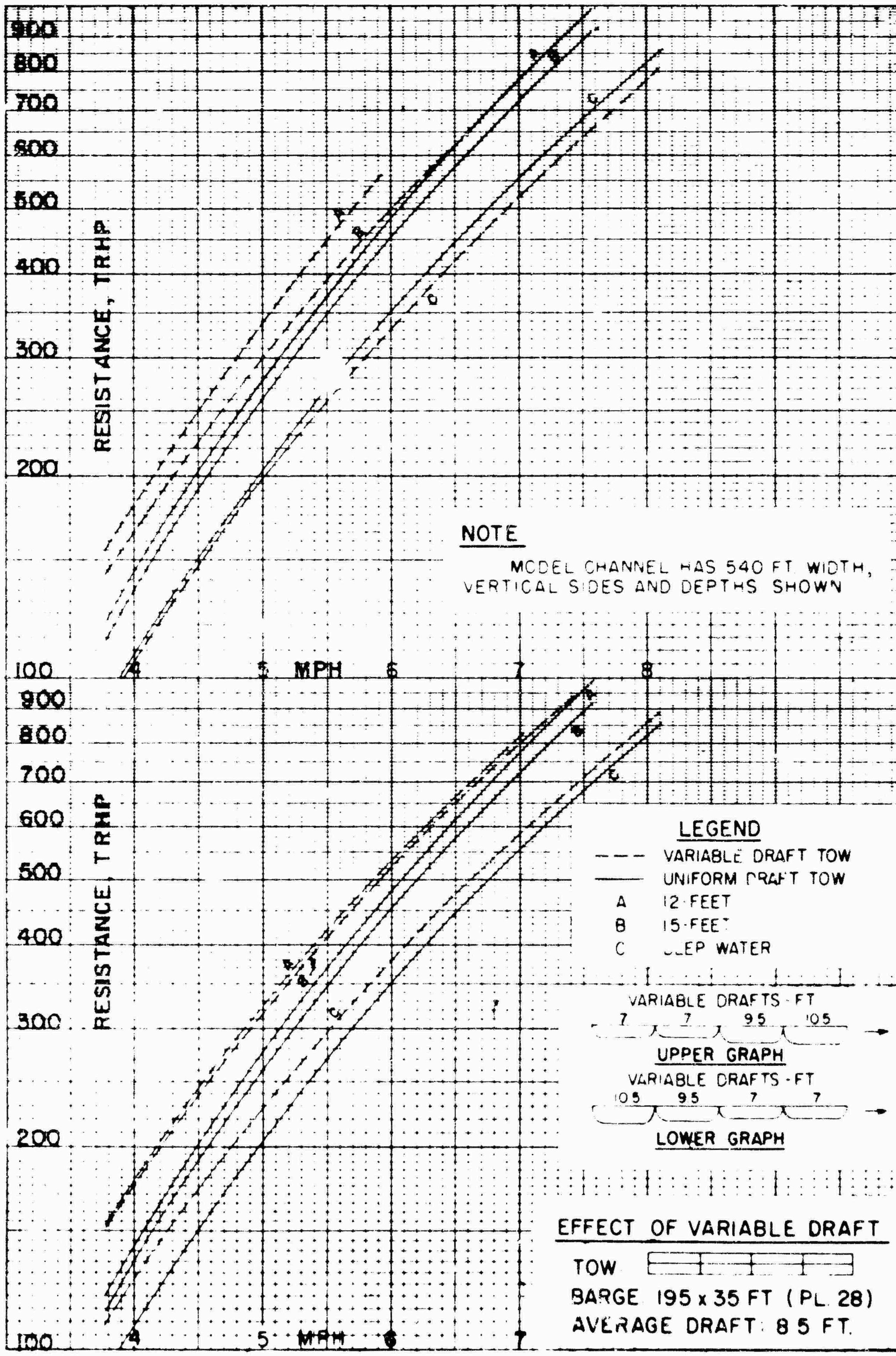
INTEGRATED TOW

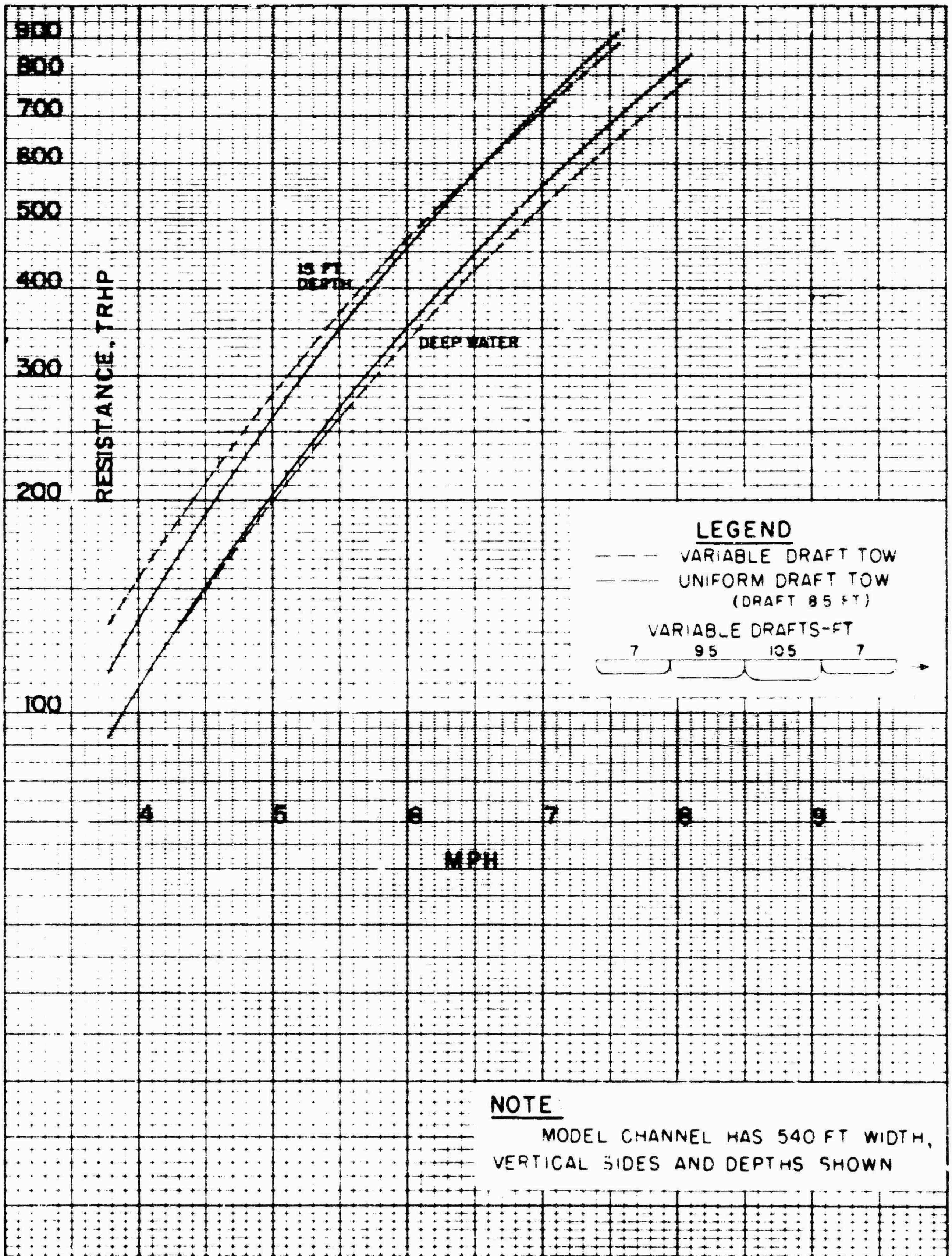
BARGE 195 x 35 FT (PL 38)

DRAFT 7.3 FT

PLATE 50


RESISTANCE, TRHP
MPH
LEGEND
PROTOTYPE
MODEL
A 11.5 FT DEPTH
B 14 " "
C 18 " "
D 28 " "
NOTES
PROTOTYPE DATA COMPUTED FOR CHANNELS OF AVERAGE DEPTHS SHOWN
MODEL CHANNEL HAS 540 FT WIDTH, VERTICAL SIDES AND DEPTHS SHOWN
MODEL & PROTOTYPE
SEMI-INTEGRATED TOW
INTEGRATED
BARGE 195 x 35 FT (PL 38)
DRAFT 7.5 FT


RESISTANCE, TRHP
900
800
700
600
500
400
300
200
100
4
5
MPH
6
7
8
A
B
C
NOTE
MODEL CHANNEL HAS 540 FT WIDTH, VERTICAL SIDES AND DEPTHS SHOWN
LEGEND
VARIABLE DRAFT TOW
UNIFORM DRAFT TOW
A 12 FEET
B 15 FEET
C DEEP WATER
VARIABLE DRAFTS - FT
7 7 9.5 10.5
UPPER GRAPH
VARIABLE DRAFTS - FT
10.5 9.5 7 7
LOWER GRAPH
EFFECT OF VARIABLE DRAFT
TOW
BARGE 195 x 35 FT (PL. 28)
AVERAGE DRAFT 8.5 FT.

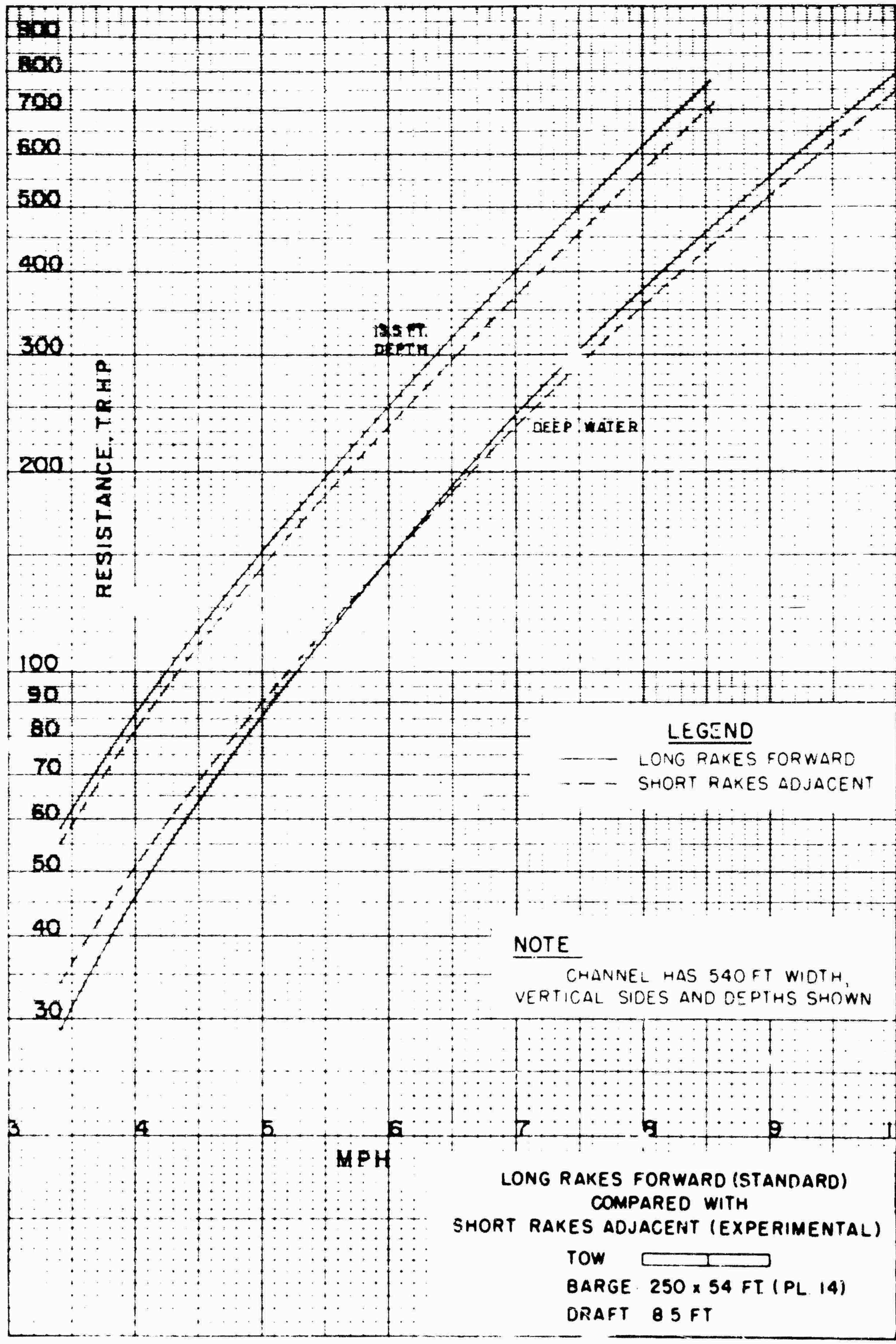


EFFECT OF VARIABLE DRAFT

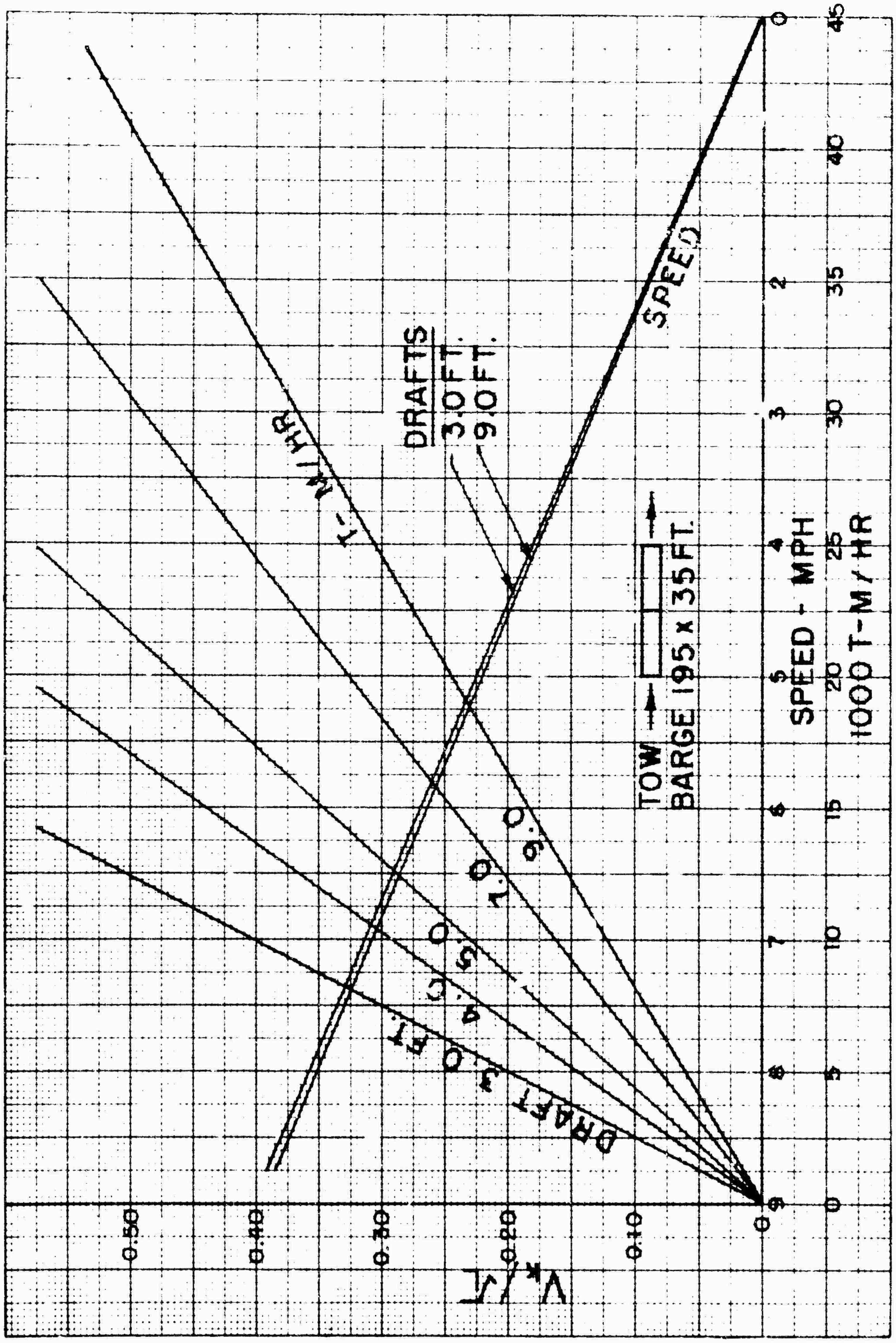
TOW

BARGE 195 x 35 FT. (PL 28)

AVERAGE DRAFT 8.5 FT.



900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
RESISTANCE, TR.H.P.
13.5 FT. DEPTH
DEEP WATER
LEGEND
LONG RAKES FORWARD
SHORT RAKES ADJACENT
NOTE
CHANNEL HAS 540 FT WIDTH, VERTICAL SIDES AND DEPTHS SHOWN
3
4
5
6
7
8
9
10
MPH
LONG RAKES FORWARD (STANDARD)
COMPARED WITH
SHORT RAKES ADJACENT (EXPERIMENTAL)
TOW
BARGE 250 x 54 FT. (PL. 14)
DRAFT 8.5 FT



DRAFTS
3.0 FT.
9.0 FT.
TOW
BARGE 195 x 35 FT.
SPEED - MPH
1000 T-M/HR
SPEED
T-M/HR
DRAFT 3.0 FT.
4.0
5.0
7.0
9.0
V_K/√L
0.10
0.20
0.30
0.40
0.50
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30
35
40
45

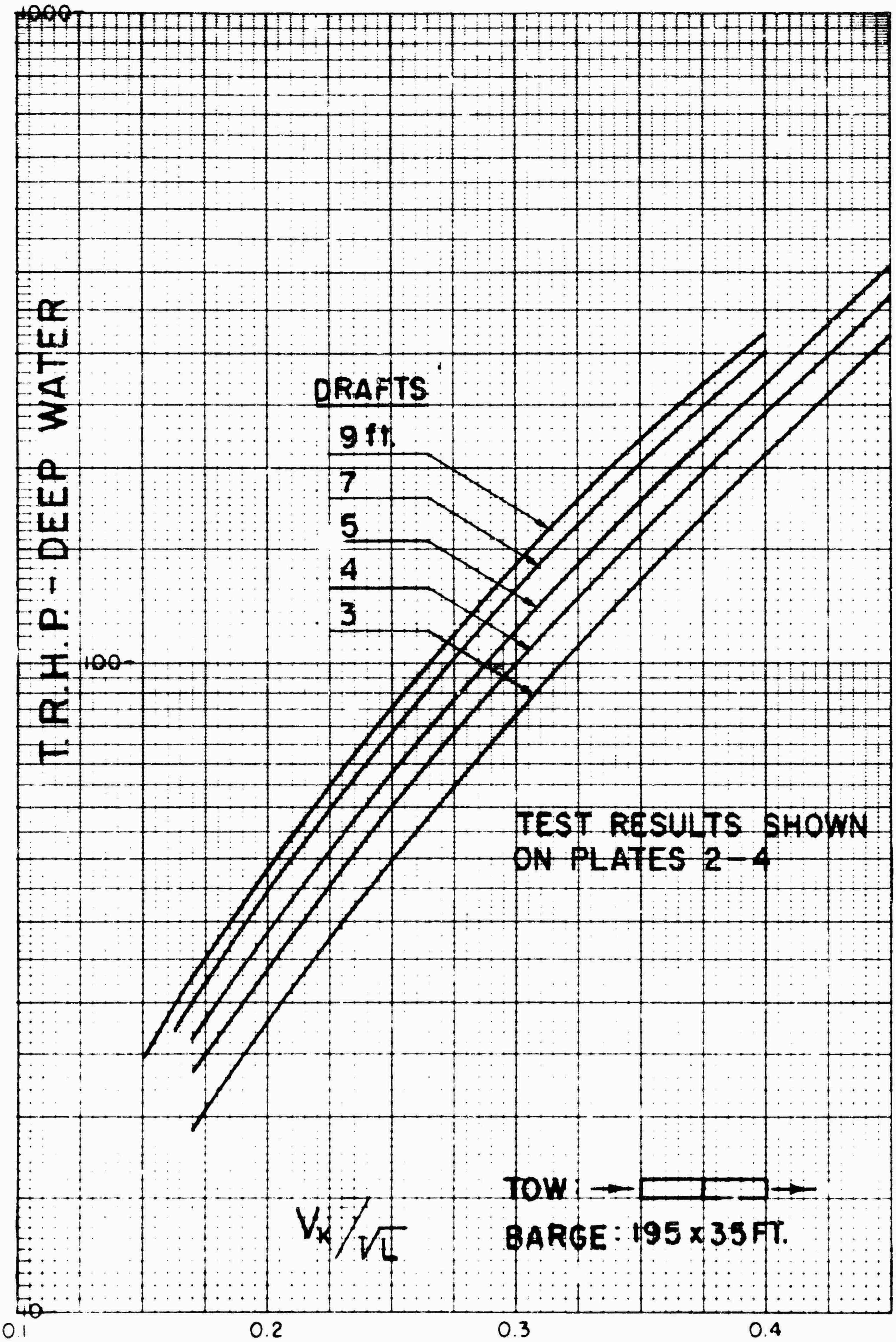
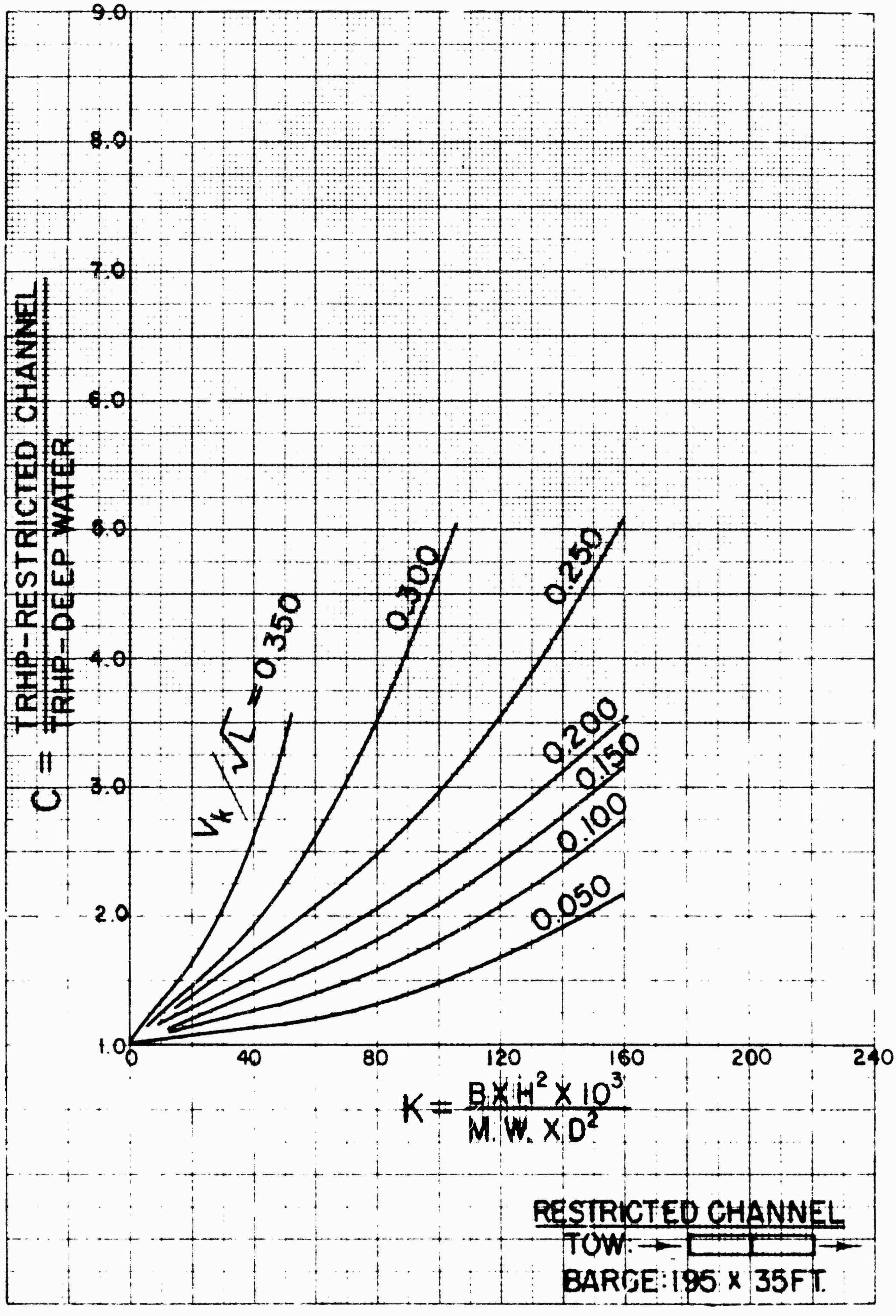
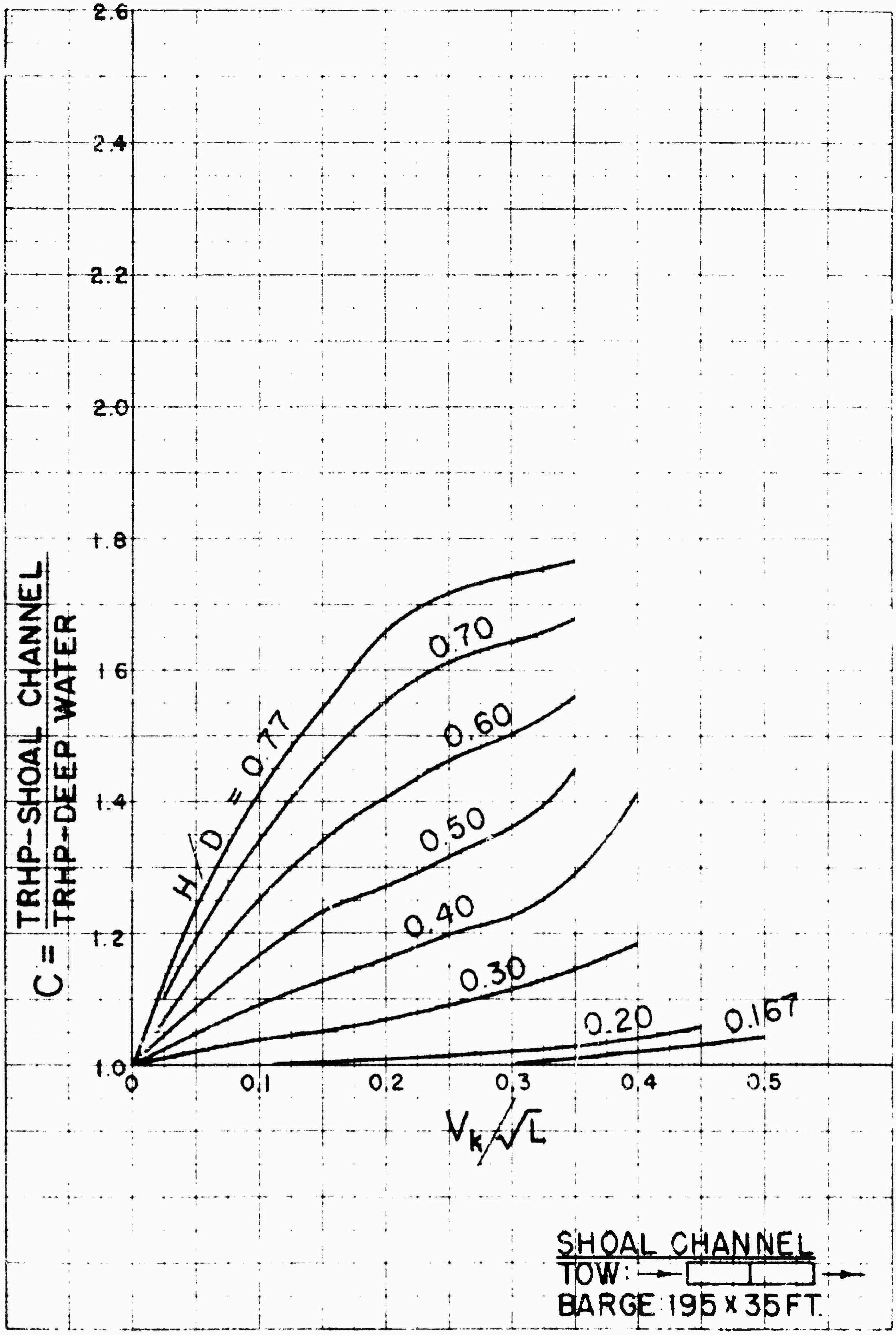

1000
100
10
T.R.H.P. - DEEP WATER
DRAFTS
9 ft
7
5
4
3
TEST RESULTS SHOWN
ON PLATES 2-4
TOW
BARGE: 195 x 35 FT.
Vk/√L
0.1
0.2
0.3
0.4

PLATE 56



$C = \frac{\text{TRHP-RESTRICTED CHANNEL}}{\text{TRHP-DEEP WATER}}$
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
40
80
120
160
200
240
$V_k / \sqrt{L} = 0.350$
0.300
0.250
0.200
0.150
0.100
0.050
$K = \frac{B \times H^2 \times 10^3}{M.W. \times D^2}$
RESTRICTED CHANNEL
TOW:
BARGE: 195 x 35 FT.



2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
0.1
0.2
0.3
0.4
0.5
$C = \frac{\text{TRHP-SHOAL CHANNEL}}{\text{TRHP-DEEP WATER}}$
$V_k/\sqrt{L}$
H/D = 0.77
0.70
0.60
0.50
0.40
0.30
0.20
0.167
SHOAL CHANNEL
TOW:
BARGE: 195 x 35 FT.

PLATE 58

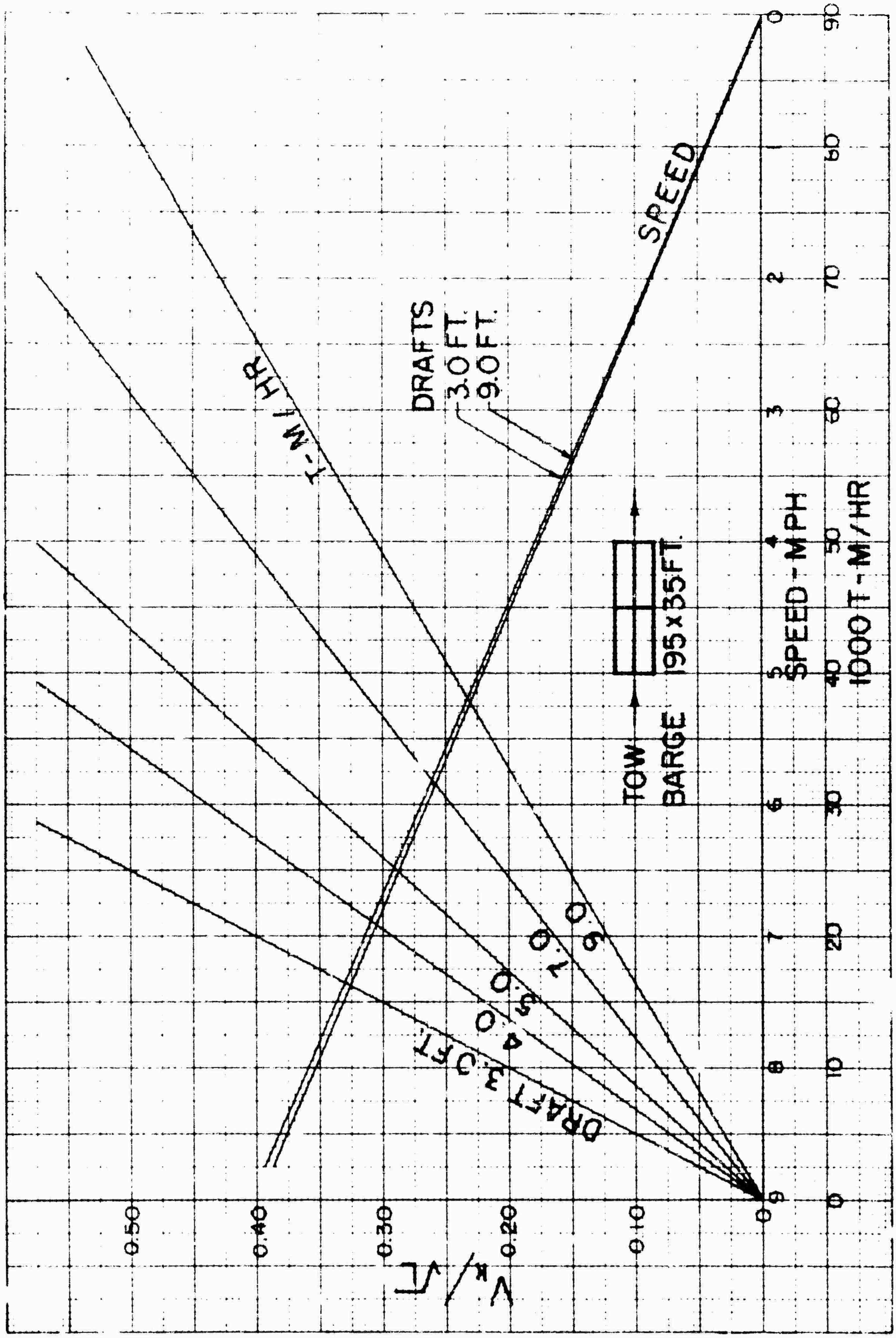

SPEED
T-M / HR
DRAFTS
3.0 FT.
9.0 FT.
TOW
BARGE
195 x 35 FT.
SPEED - MPH
1000 T-M / HR
DRAFT 3.0 FT.
4.0
5.0
7.0
9.0
$V_k / \sqrt{L}$
0.50
0.40
0.30
0.20
0.10
0

PLATE 59

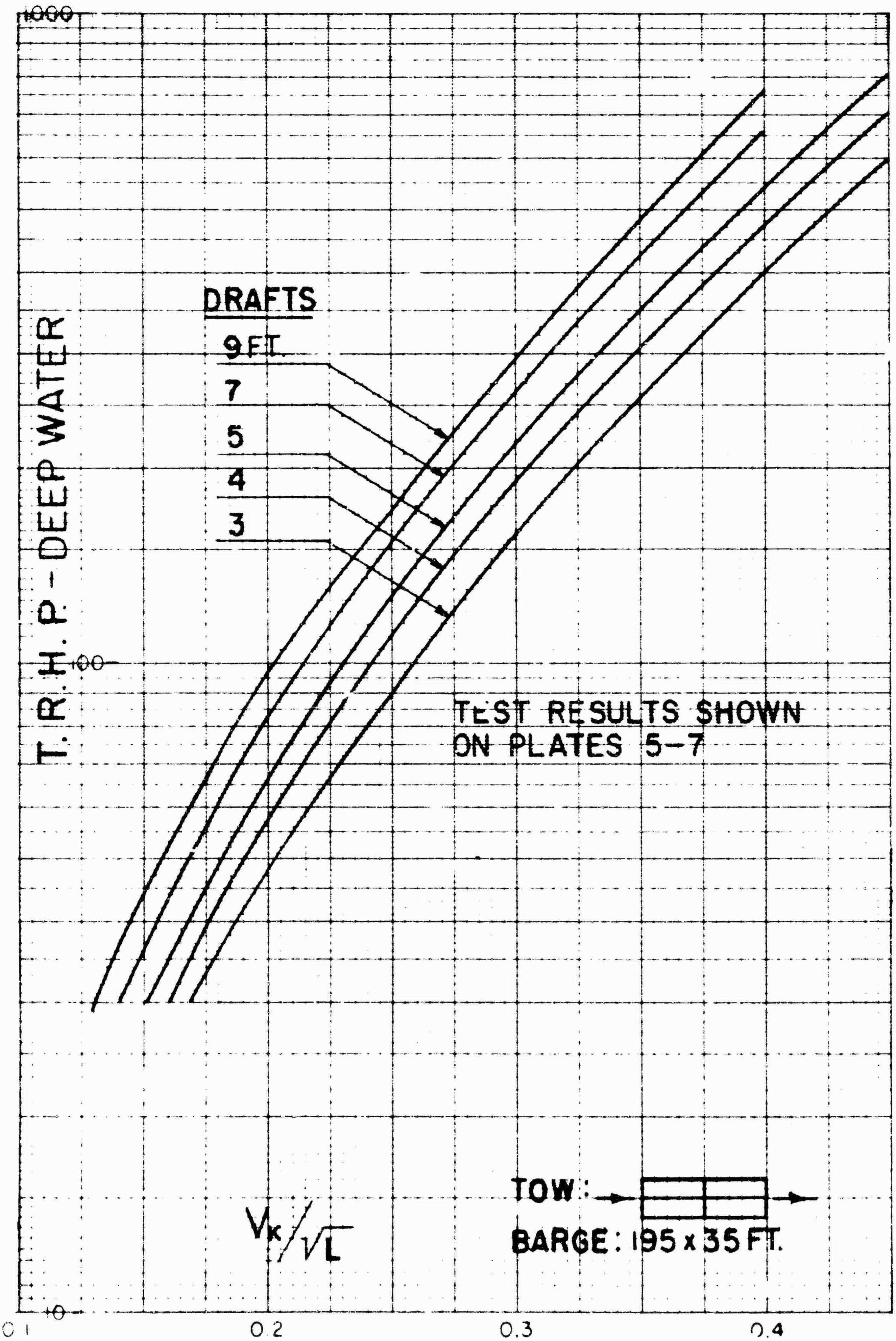
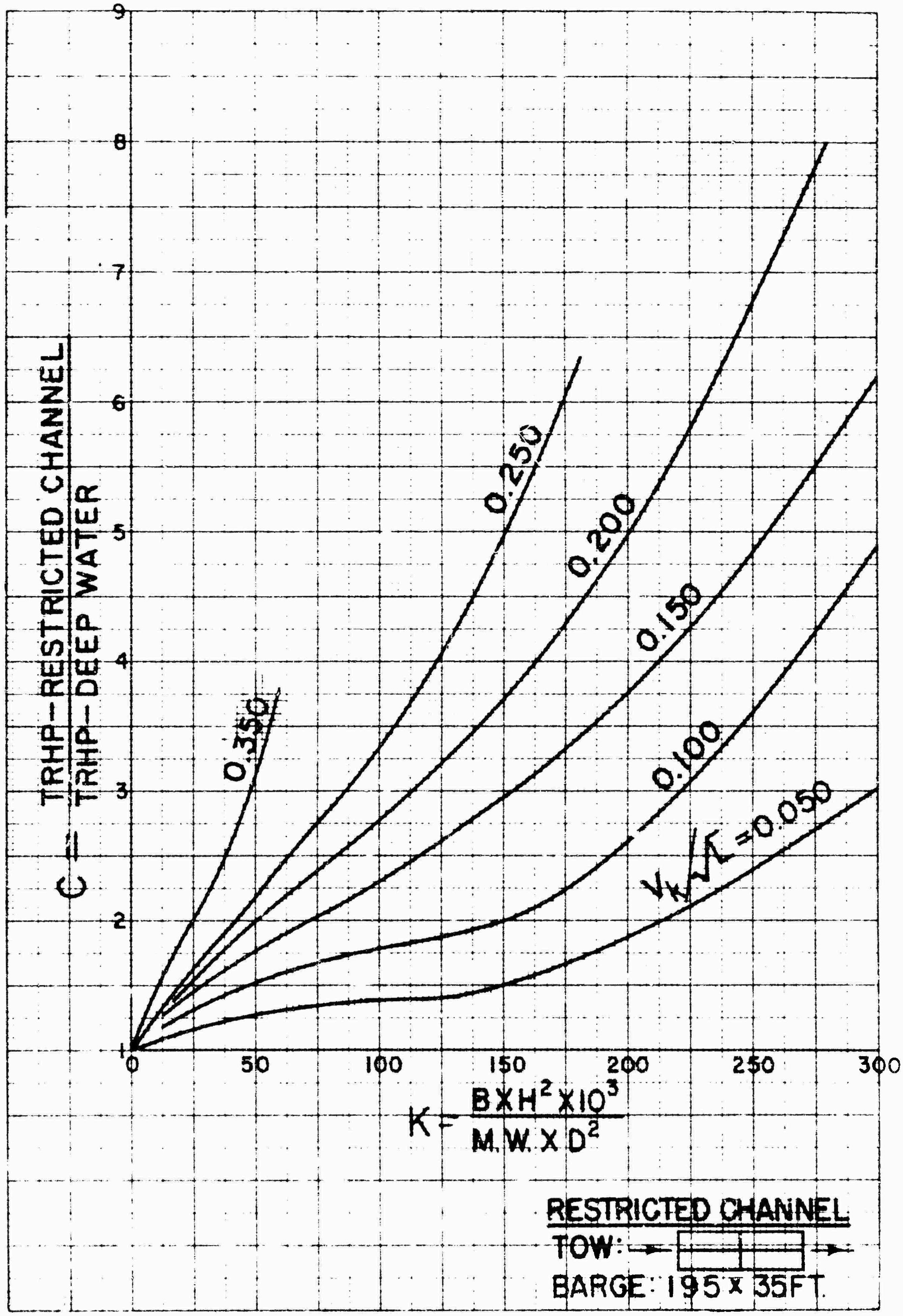
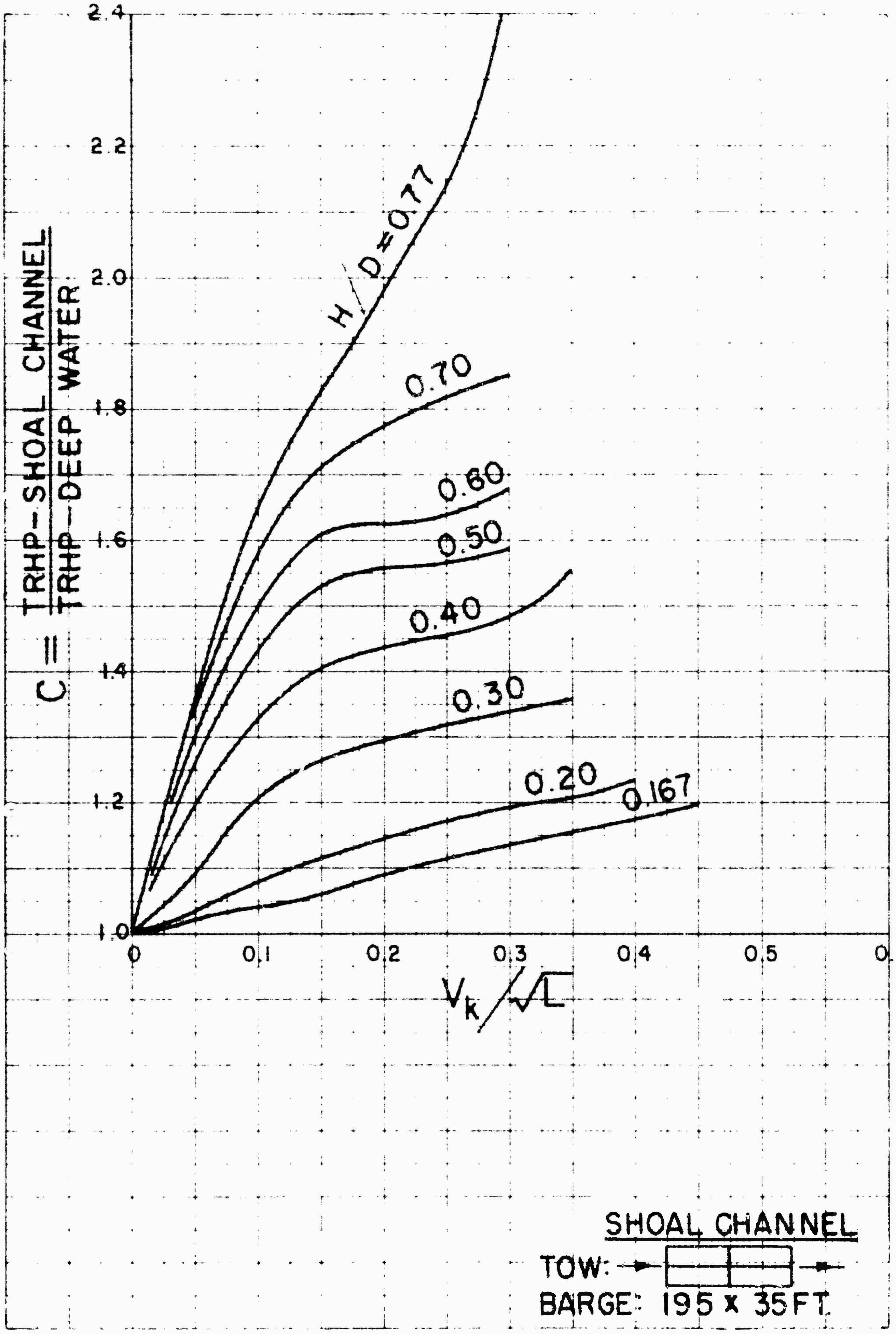

1000
100
10
T. R. H. P. - DEEP WATER
DRAFTS
9 FT.
7
5
4
3
TEST RESULTS SHOWN
ON PLATES 5-7
TOW:
BARGE: 195 x 35 FT.
$V_K/\sqrt{L}$
0.1
0.2
0.3
0.4

PLATE 6C

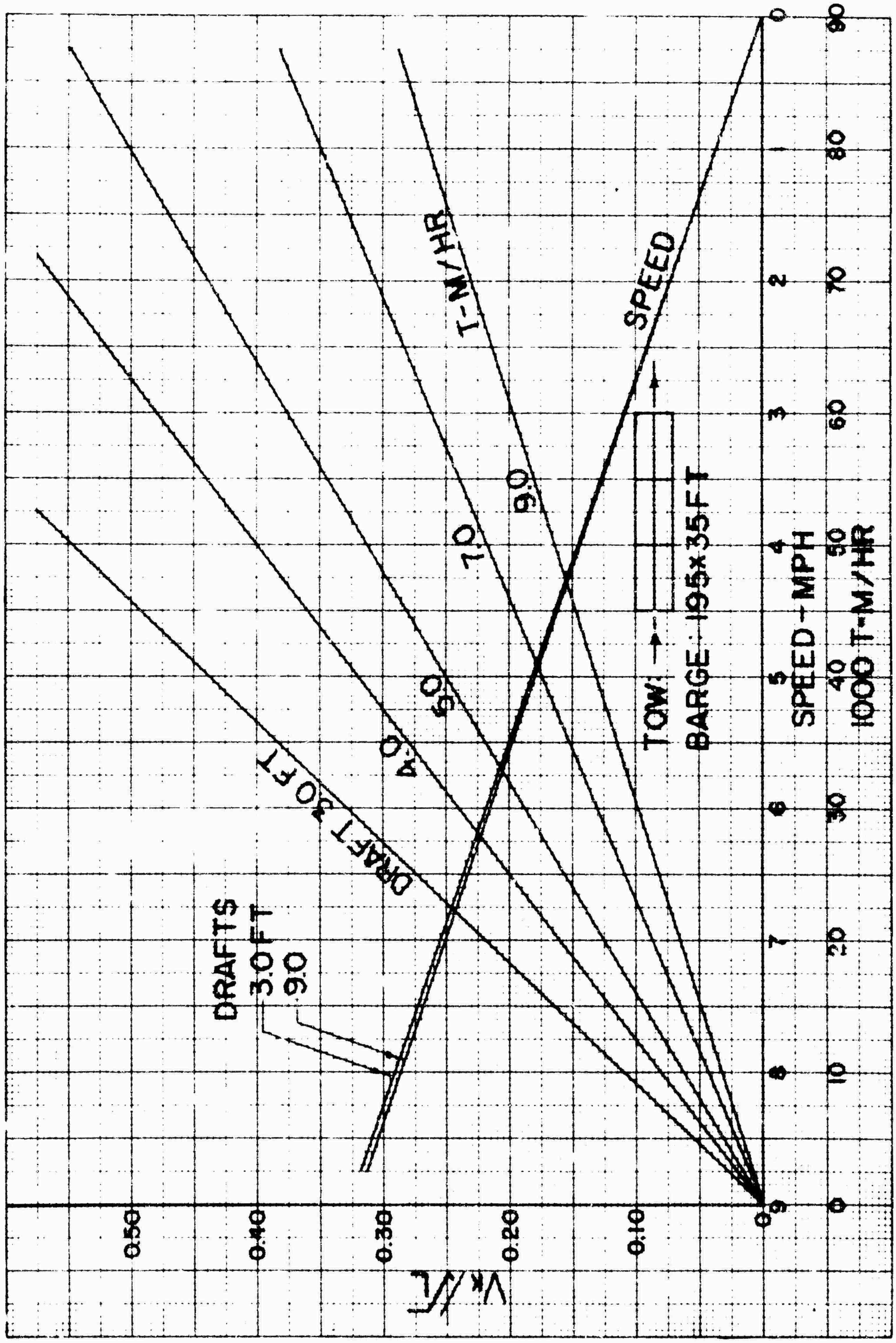


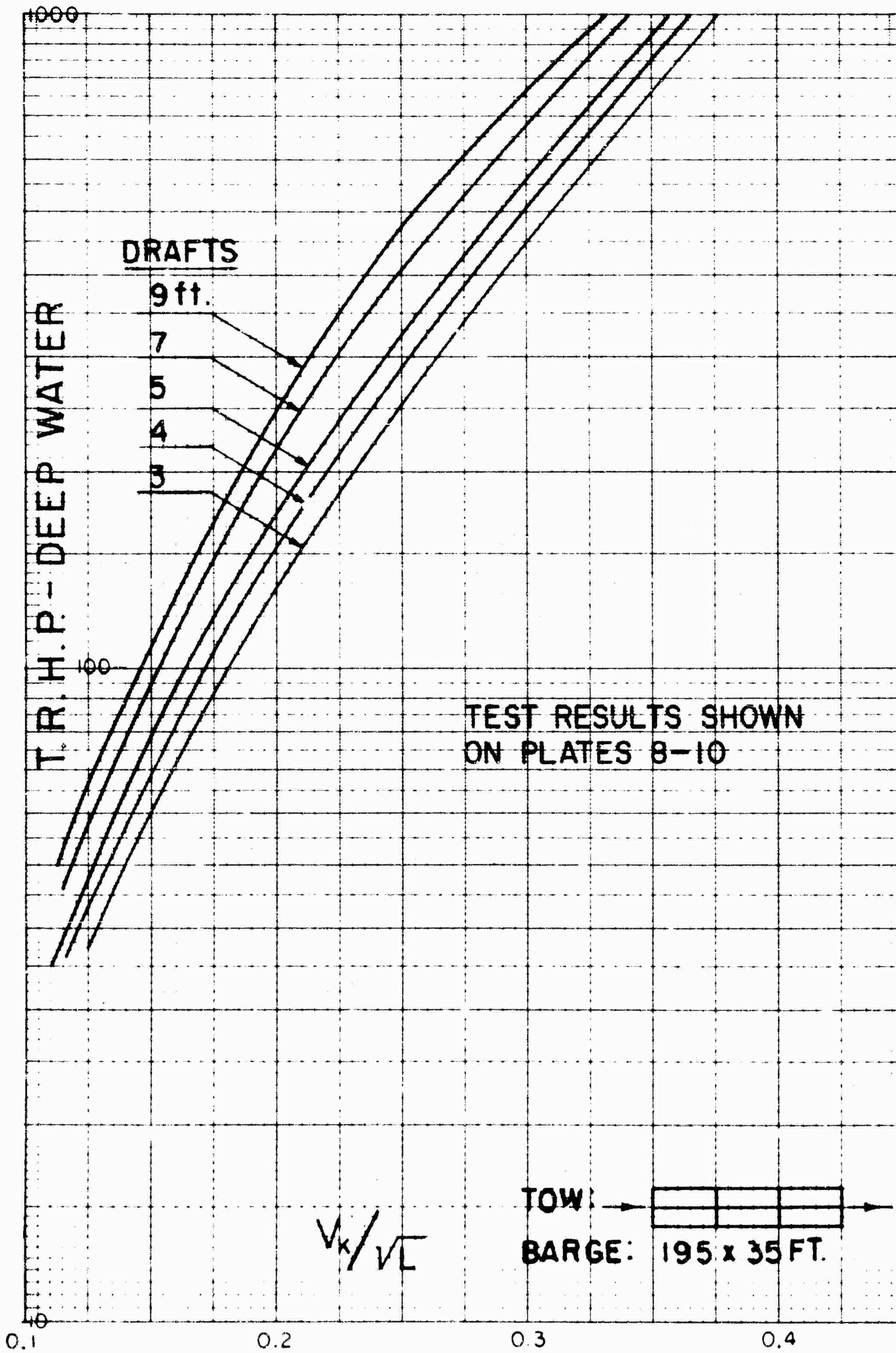
$C = \frac{\text{TRHP—RESTRICTED CHANNEL}}{\text{TRHP—DEEP WATER}}$
$K = \frac{B \times H^2 \times 10^3}{M.W. \times D^2}$
0.350
0.250
0.200
0.150
0.100
$V_K/\sqrt{L} = 0.050$
0
50
100
150
200
250
300
1
2
3
4
5
6
7
8
9
RESTRICTED CHANNEL
TOW:
BARGE: 195 x 35FT.



2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
0.1
0.2
0.3
0.4
0.5
0.6
C = TRHP - SHOAL CHANNEL / TRHP - DEEP WATER
V_k / √L
H/D = 0.77
0.70
0.60
0.50
0.40
0.30
0.20
0.167
SHOAL CHANNEL
TOW:
BARGE: 195 x 35 FT.

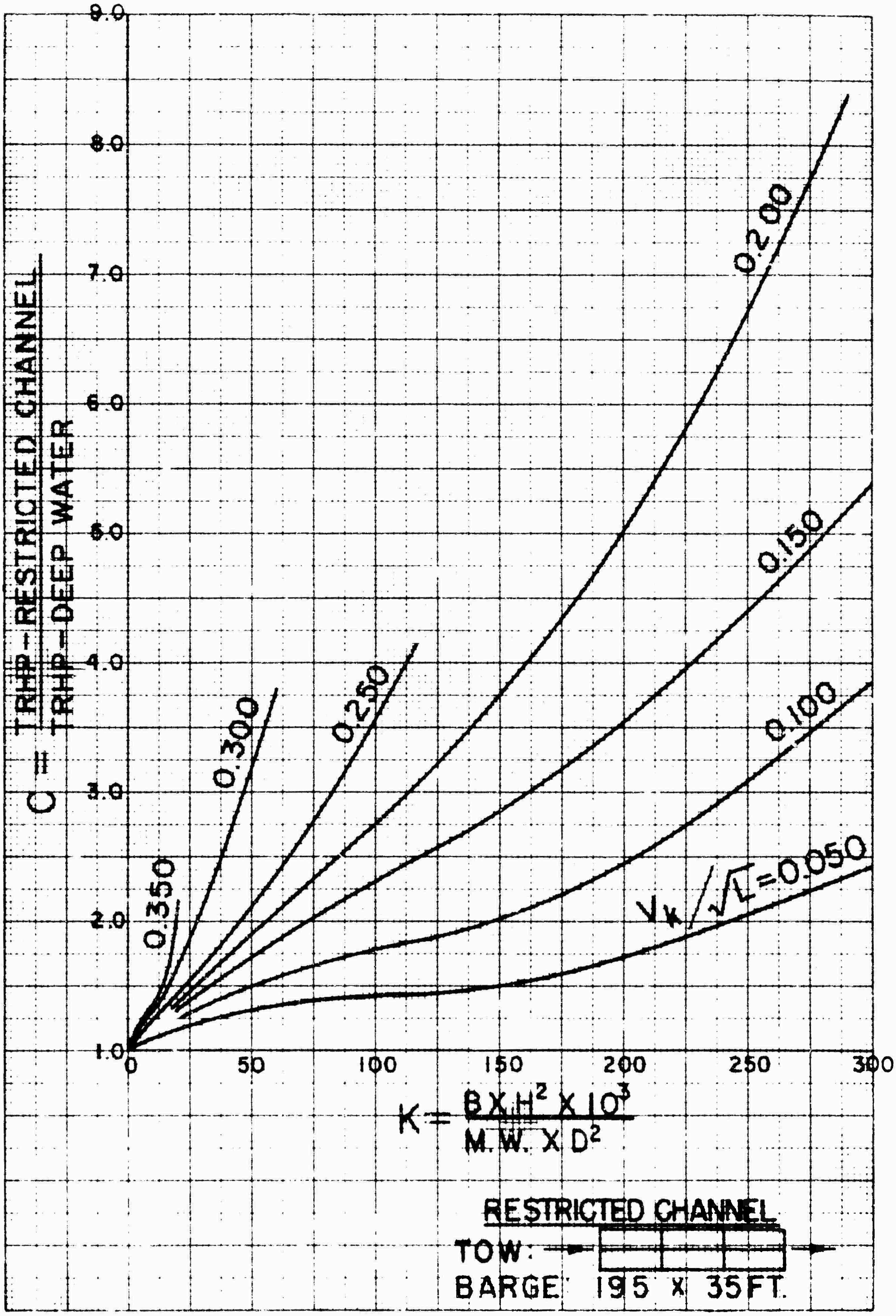
PLATE 42


SPEED
T-M/HR
9.0
7.0
6.0
4.0
DRAFT 3.0 FT
DRAFTS
3.0 FT
9.0
TOW
BARGE 195x35 FT
SPEED-MPH
1000 T-M/HR
$V_k/\sqrt{L}$
0.50
0.40
0.30
0.20
0.10
0
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90

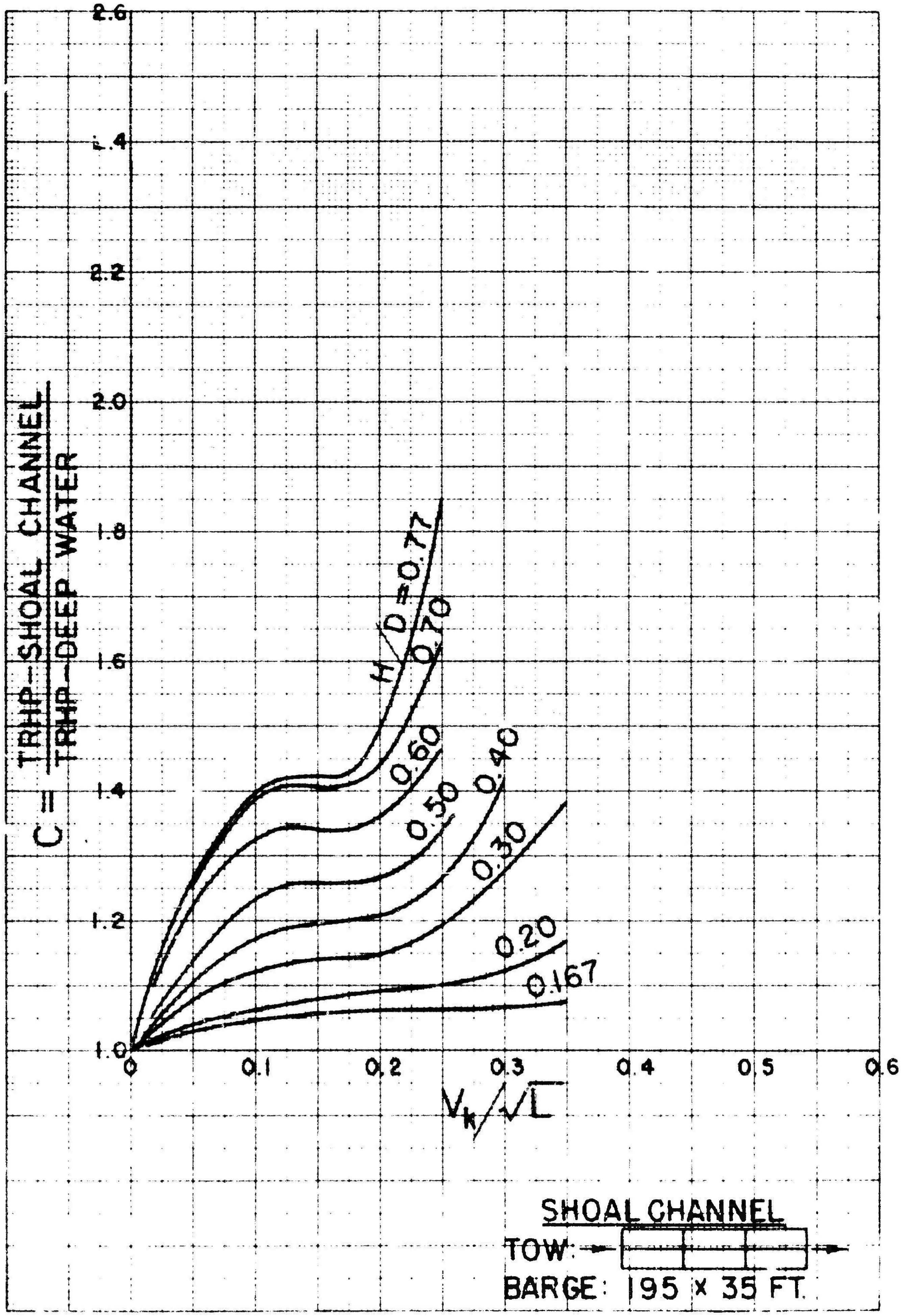


1000
100
10
0.1
0.2
0.3
0.4
T. R. H. P. - DEEP WATER
DRAFTS
9 ft.
7
5
4
3
TEST RESULTS SHOWN ON PLATES 8-10
TOW:
BARGE: 195 x 35 FT.
$V_k/\sqrt{L}$

PLATE 64

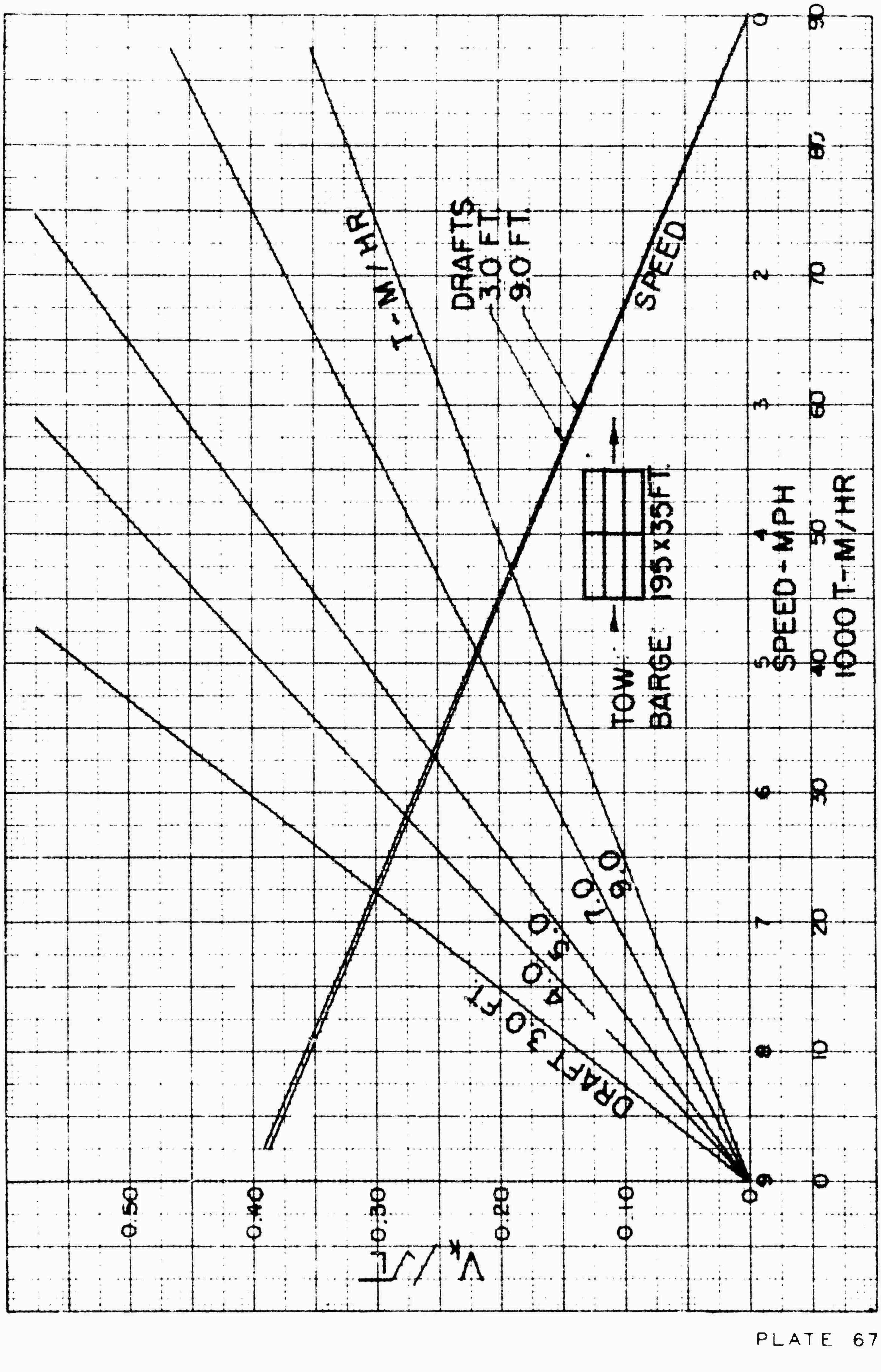


$C = \frac{\text{TRHP - RESTRICTED CHANNEL}}{\text{TRHP - DEEP WATER}}$
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
50
100
150
200
250
300
0.350
0.300
0.250
0.200
0.150
0.100
$V_K/\sqrt{L} = 0.050$
$K = \frac{B \times H^2 \times 10^3}{M.W. \times D^2}$
RESTRICTED CHANNEL
TOW:
BARGE 195 X 35 FT.



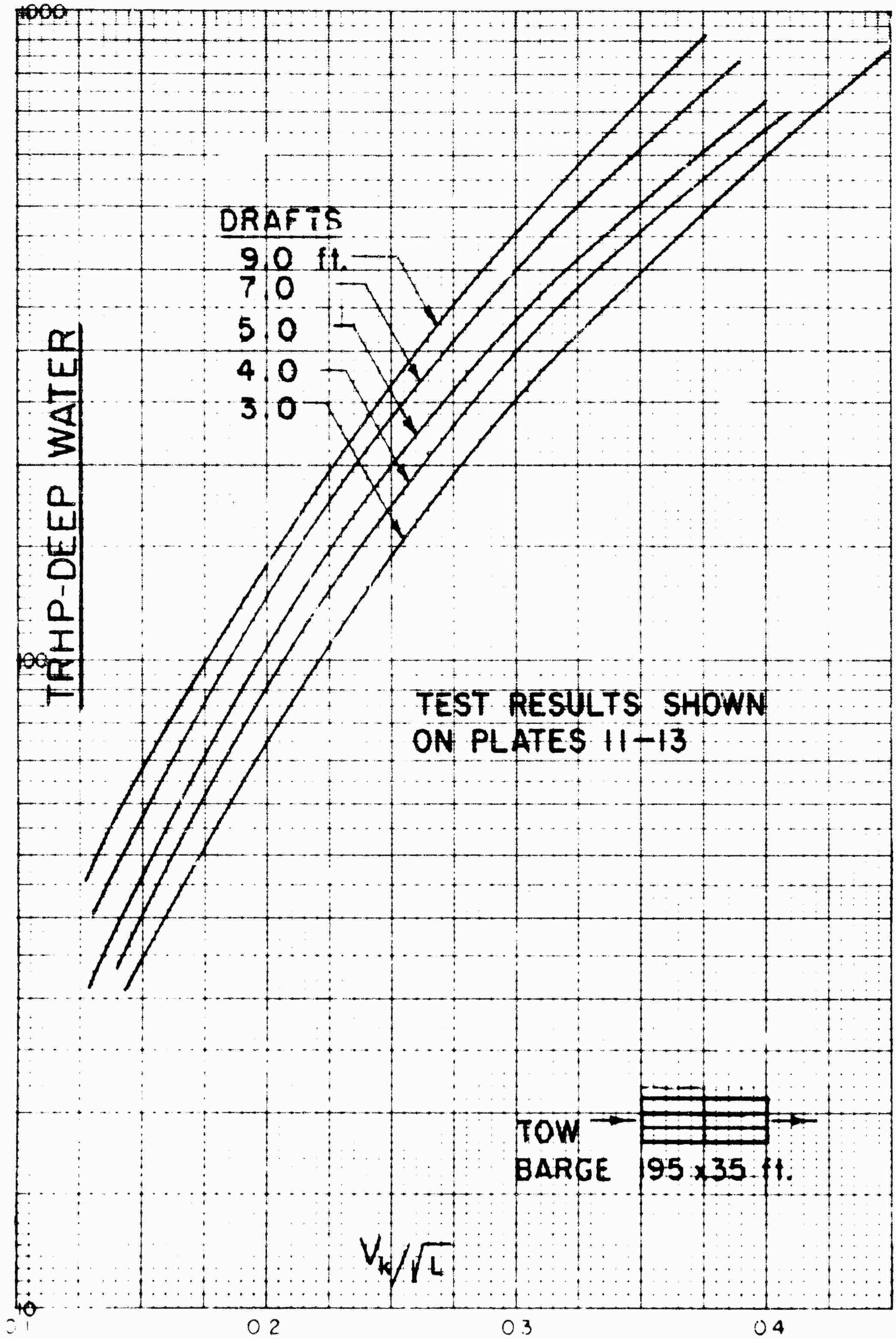
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
C = TRHP—SHOAL CHANNEL / TRHP—DEEP WATER
H/D = 0.77
0.70
0.60
0.50
0.40
0.30
0.20
0.167
0
0.1
0.2
0.3
0.4
0.5
0.6
$V_k/\sqrt{L}$
SHOAL CHANNEL
TOW:
BARGE: 195 × 35 FT.

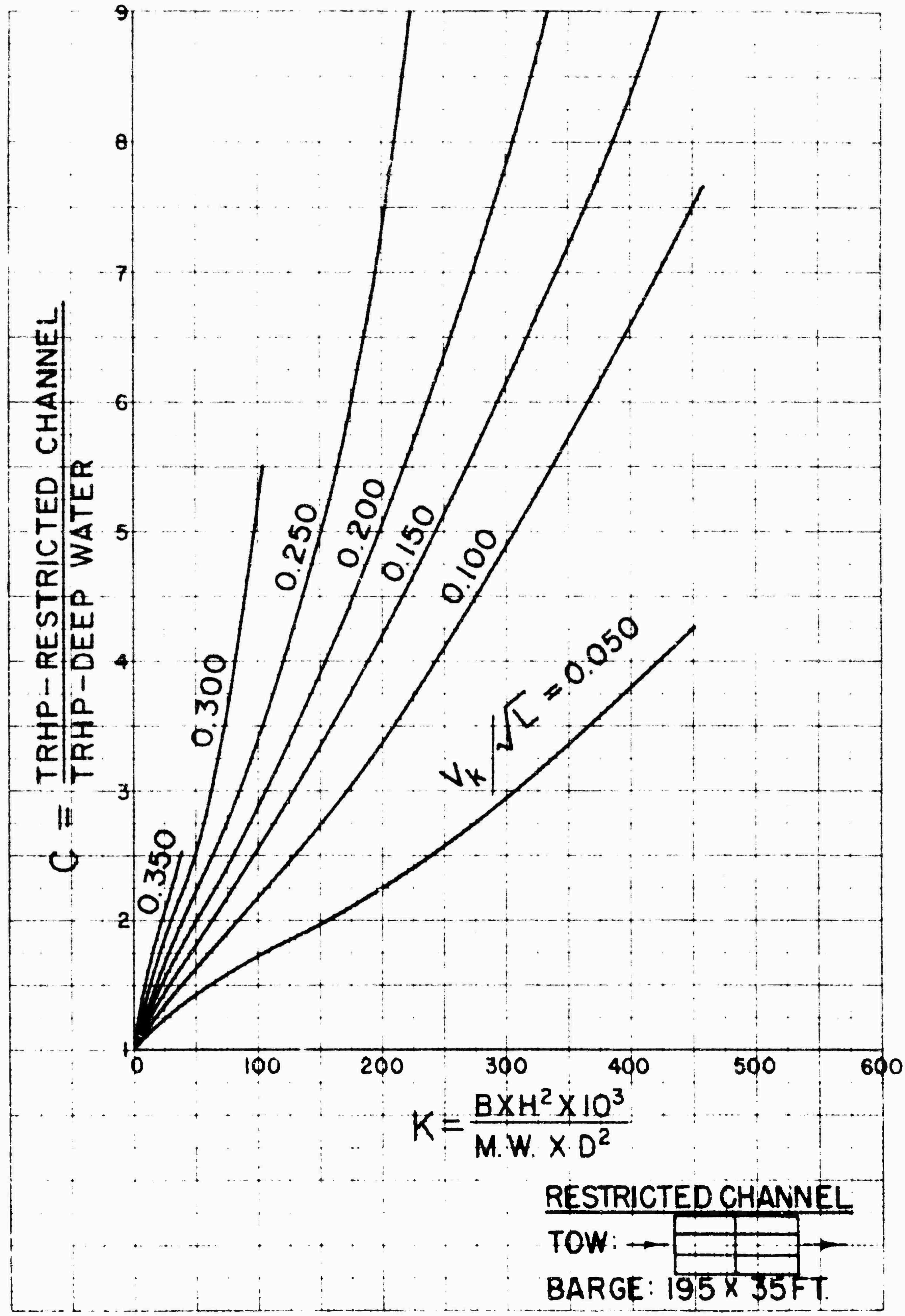
PLATE 66



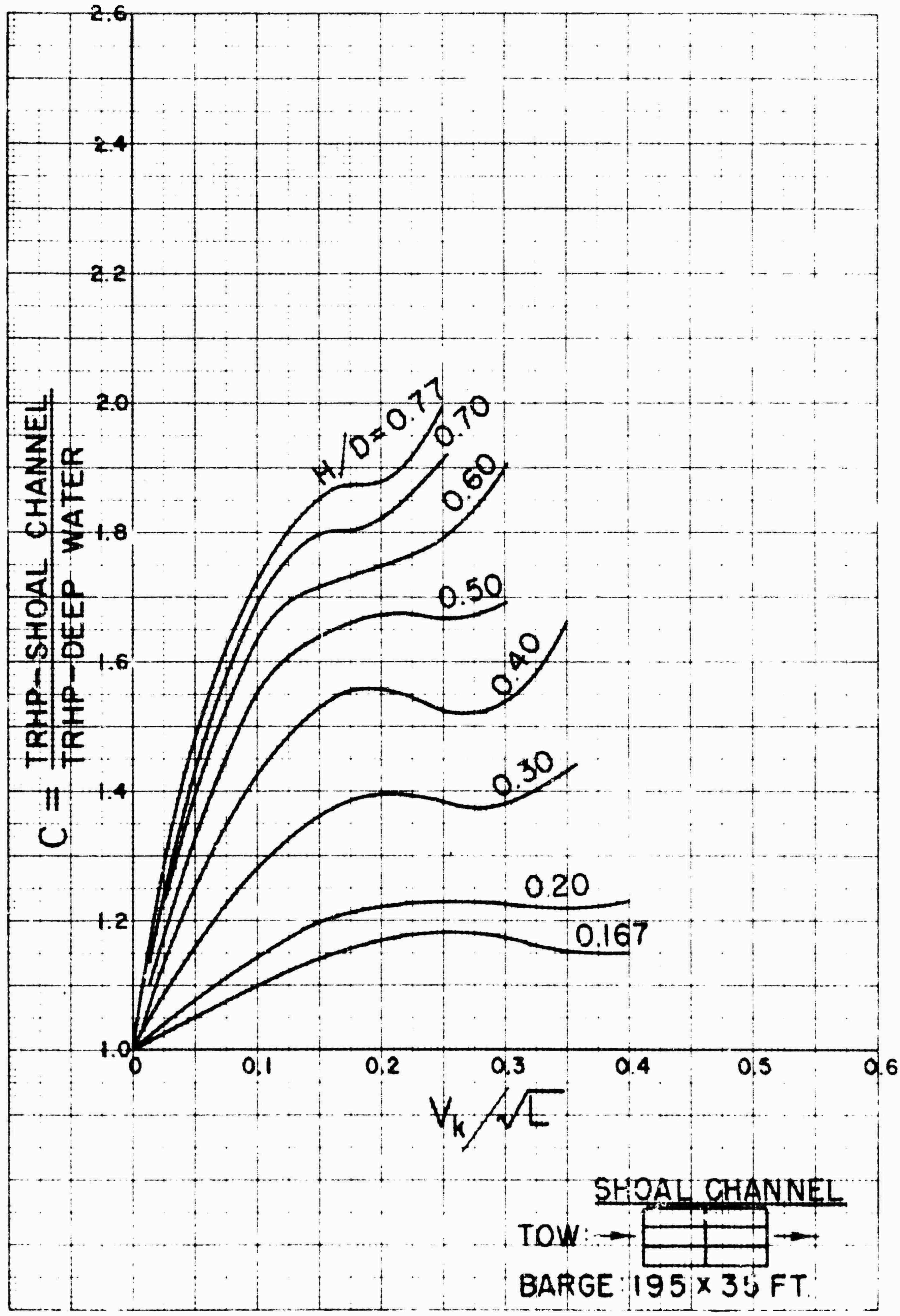
V*/√L
0.50
0.40
0.30
0.20
0.10
0
SPEED - MPH
1000 T-M/HR
T-M/HR
SPEED
DRAFTS
3.0 FT.
9.0 FT.
TOW
BARGE 195 x 35 FT.
DRAFT 3.0 FT.
4.0
5.0
7.0
9.0

PLATE 67


1000
100
10
0.1
0.2
0.3
0.4
TRHP-DEEP WATER
$V_k/\sqrt{L}$
DRAFTS
9.0 ft.
7.0
5.0
4.0
3.0
TEST RESULTS SHOWN ON PLATES 11-13
TOW
BARGE 195 x 35 ft.

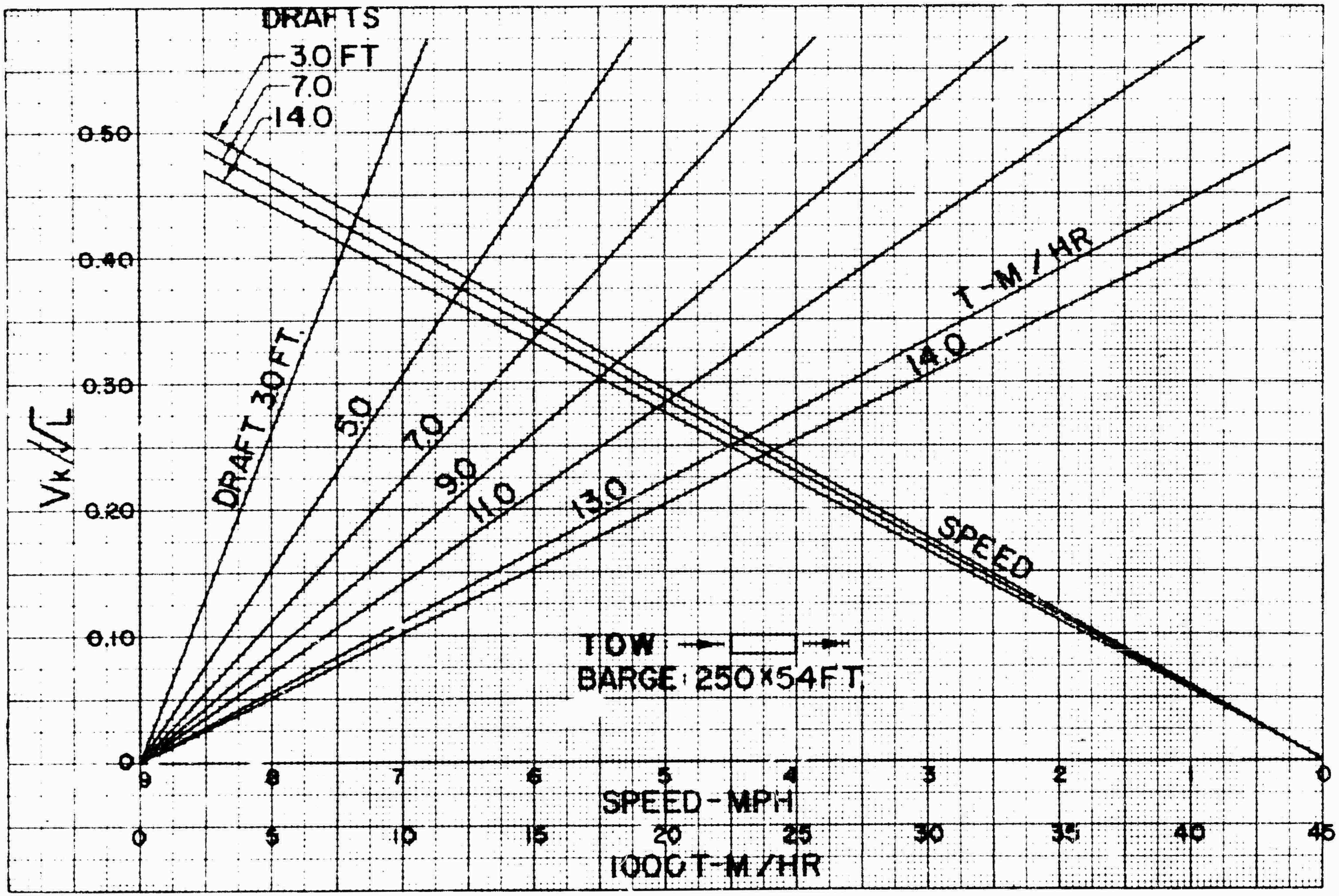


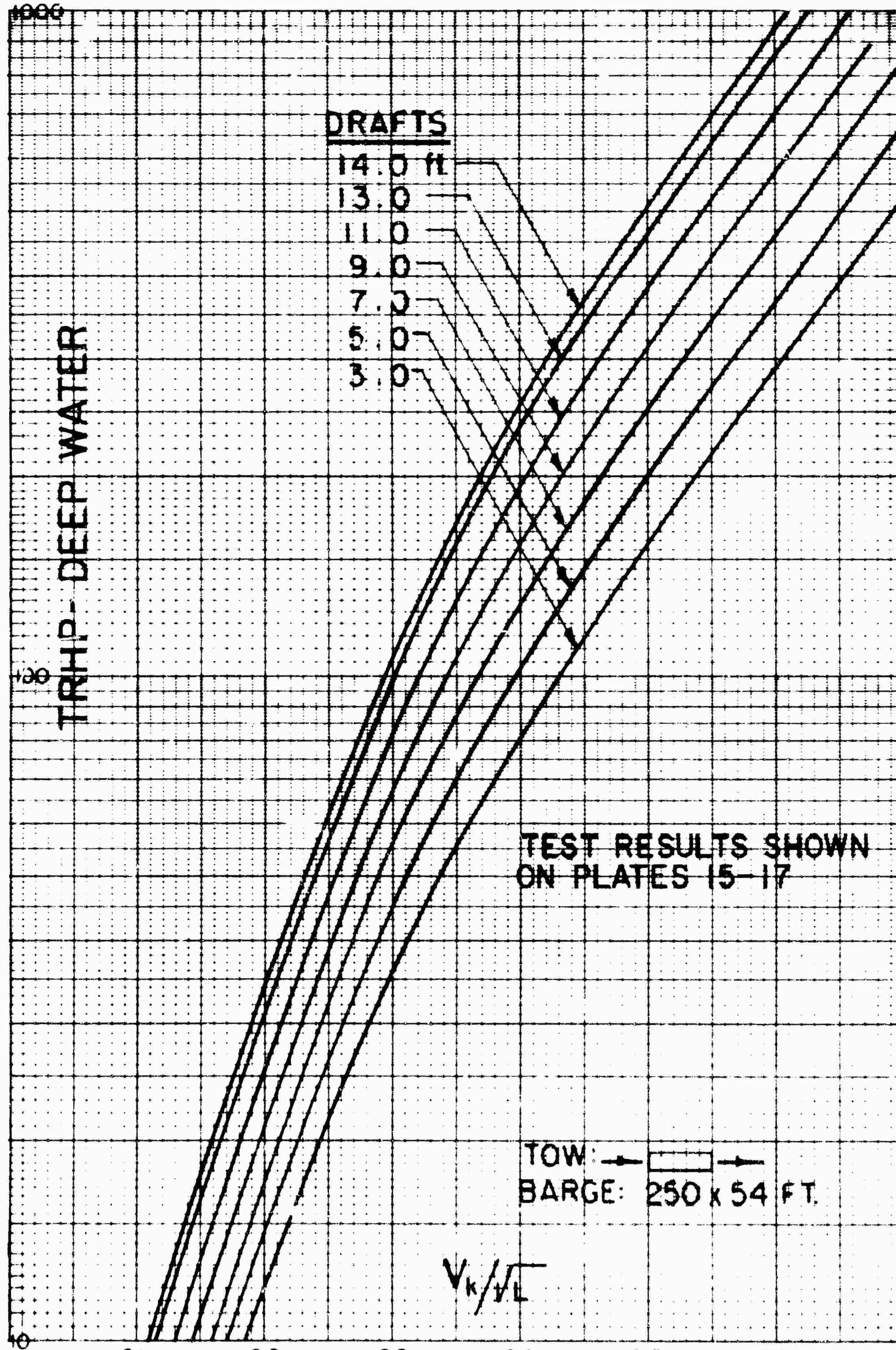
C = TRHP-RESTRICTED CHANNEL / TRHP-DEEP WATER
1
2
3
4
5
6
7
8
9
0
100
200
300
400
500
600
0.350
0.300
0.250
0.200
0.150
0.100
Vk/√L = 0.050
K = B X H² X 10³ / M.W. X D²
RESTRICTED CHANNEL
TOW:
BARGE: 195 X 35 FT.



C = TRHP—SHOAL CHANNEL / TRHP—DEEP WATER
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
0.1
0.2
0.3
0.4
0.5
0.6
Vk/√L
H/D=0.77
0.70
0.60
0.50
0.40
0.30
0.20
0.167
SHOAL CHANNEL
TOW:
BARGE 195 x 35 FT

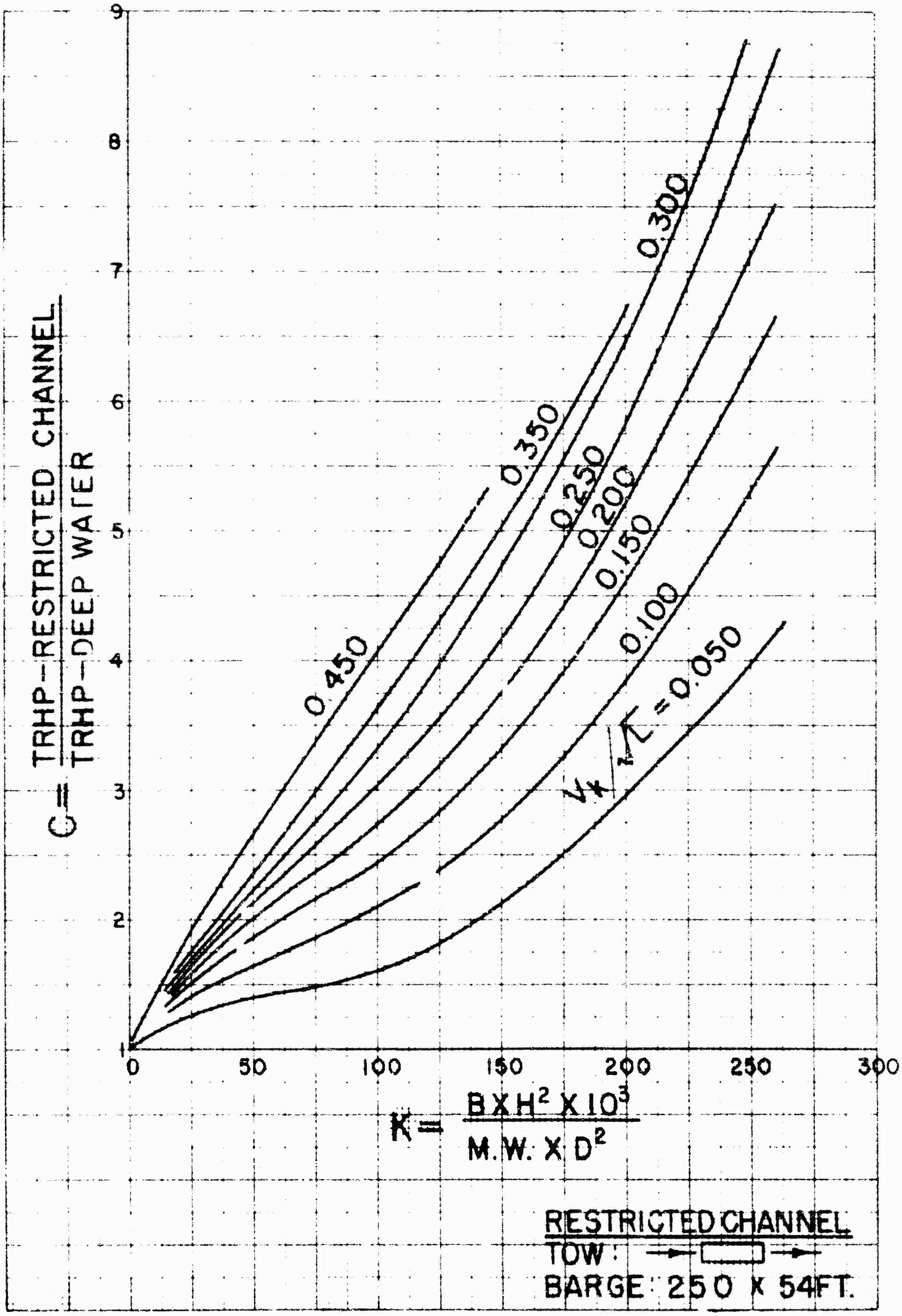
PLATE


DRAFTS
3.0 FT
7.0
14.0
DRAFT 3.0 FT.
5.0
7.0
9.0
11.0
13.0
14.0
T-M / HR
SPEED
TOW
BARGE 250 X 54 FT.
$V_K/\sqrt{L}$
0.50
0.40
0.30
0.20
0.10
0
9
8
7
6
5
4
3
2
1
0
SPEED - MPH
0
5
10
15
20
25
30
35
40
45
1000 T-M / HR

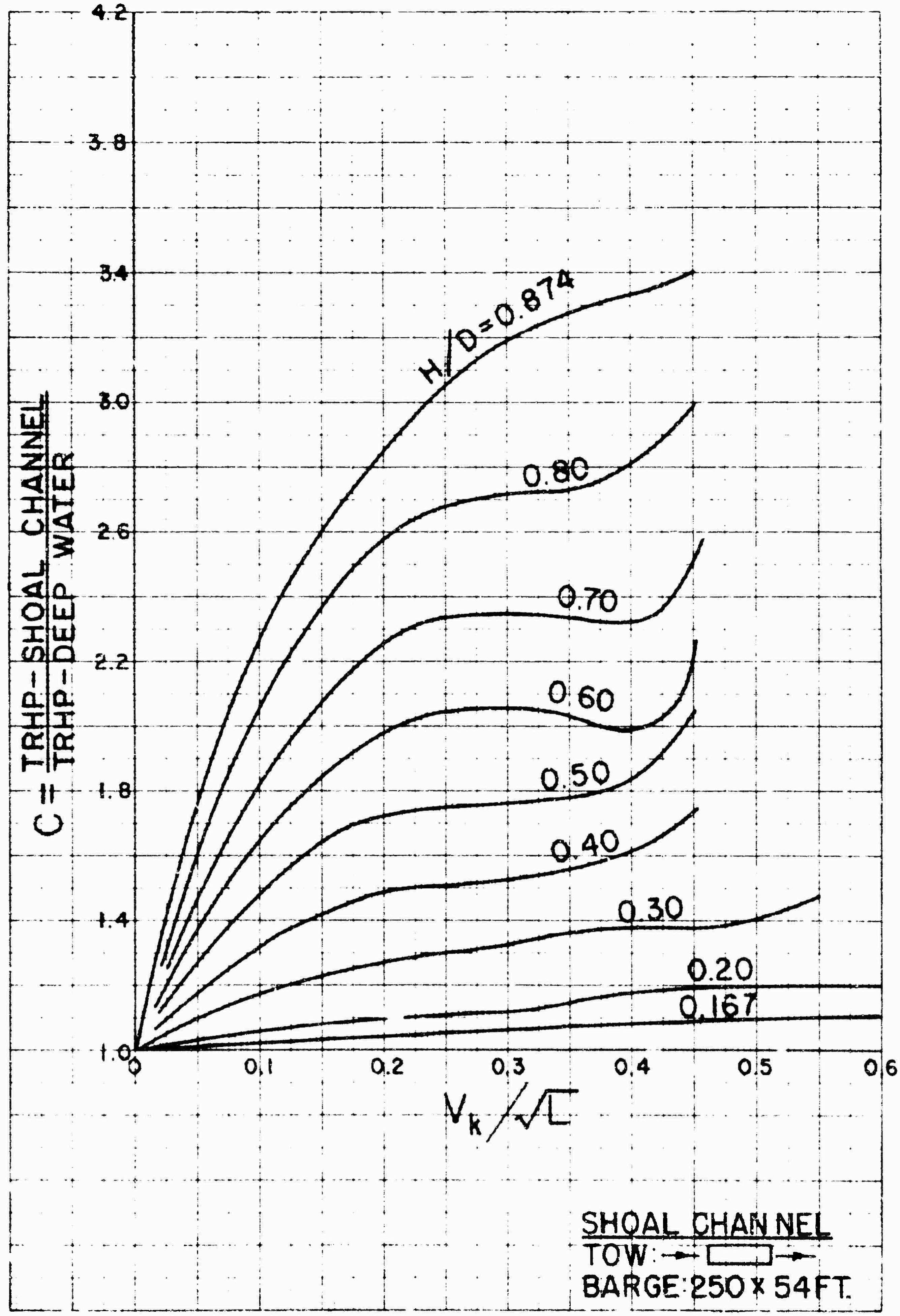


1000
100
10
TRHP- DEEP WATER
DRAFTS
14.0 ft
13.0
11.0
9.0
7.0
5.0
3.0
TEST RESULTS SHOWN
ON PLATES 15-17
TOW:
BARGE: 250 x 54 FT.
Vk/√L
0.1
0.2
0.3
0.4
0.5
0.6

PLATE 72

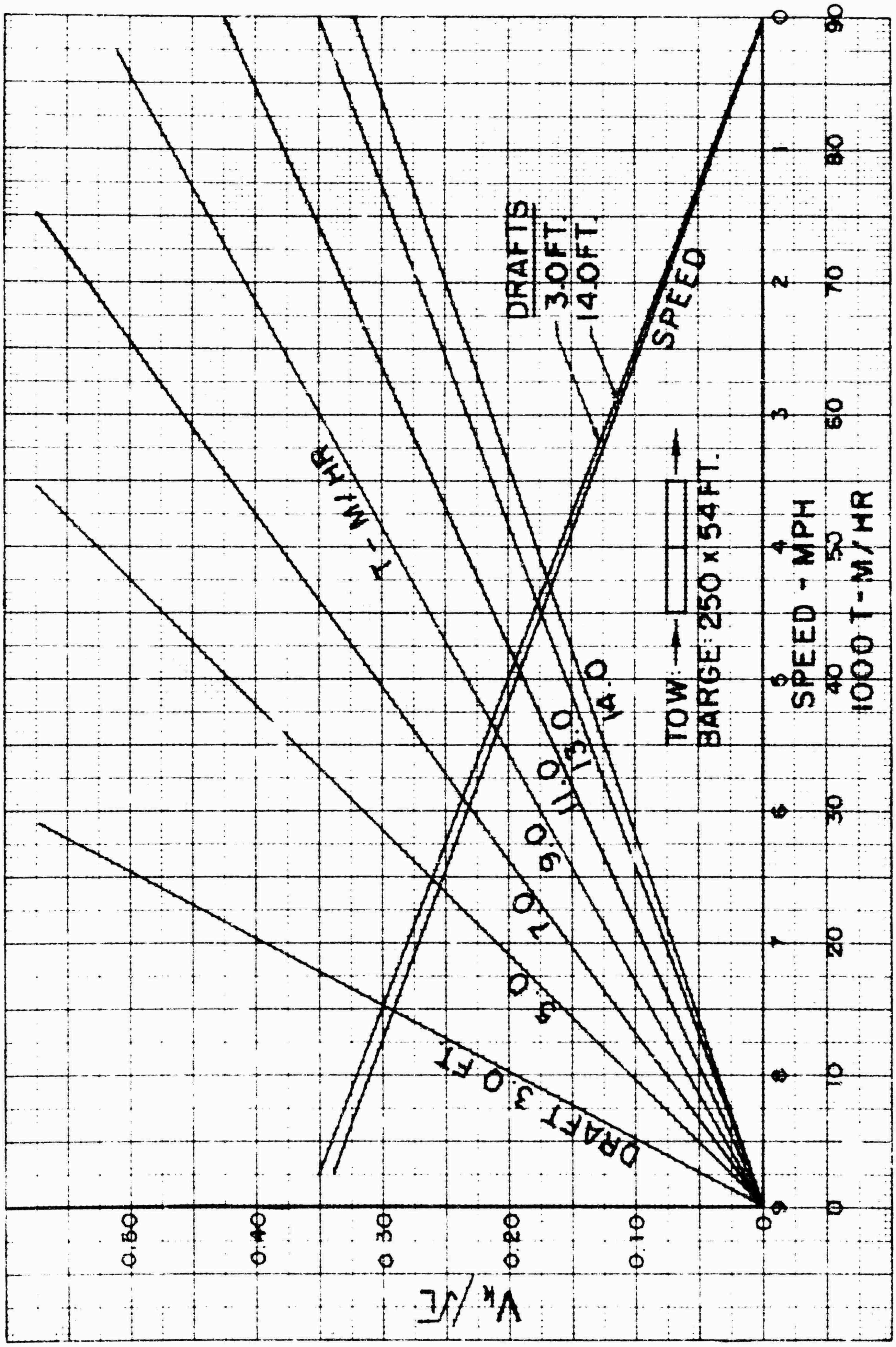


9
8
7
6
5
4
3
2
1
0
50
100
150
200
250
300
C = TRHP–RESTRICTED CHANNEL / TRHP–DEEP WATER
K = B X H² X 10³ / M.W. X D²
0.450
0.350
0.300
0.250
0.200
0.150
0.100
$V_k/\sqrt{L}$ = 0.050
RESTRICTED CHANNEL
TOW:
BARGE: 250 X 54FT.



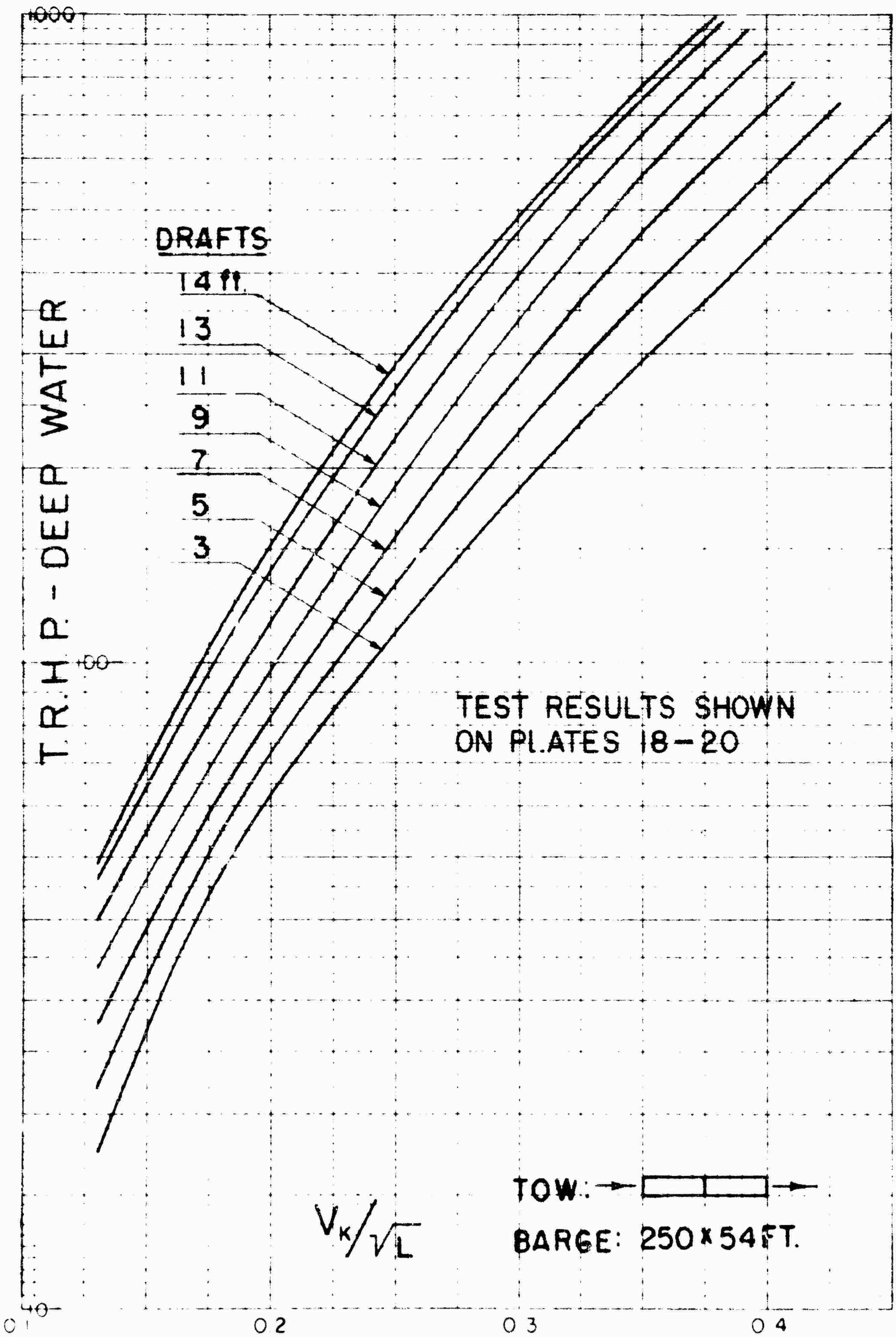
4.2
3.8
3.4
3.0
2.6
2.2
1.8
1.4
1.0
C = TRHP- SHOAL CHANNEL / TRHP- DEEP WATER
H/D=0.874
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.167
0
0.1
0.2
0.3
0.4
0.5
0.6
Vk/√L
SHOAL CHANNEL
TOW:
BARGE: 250 x 54 FT.

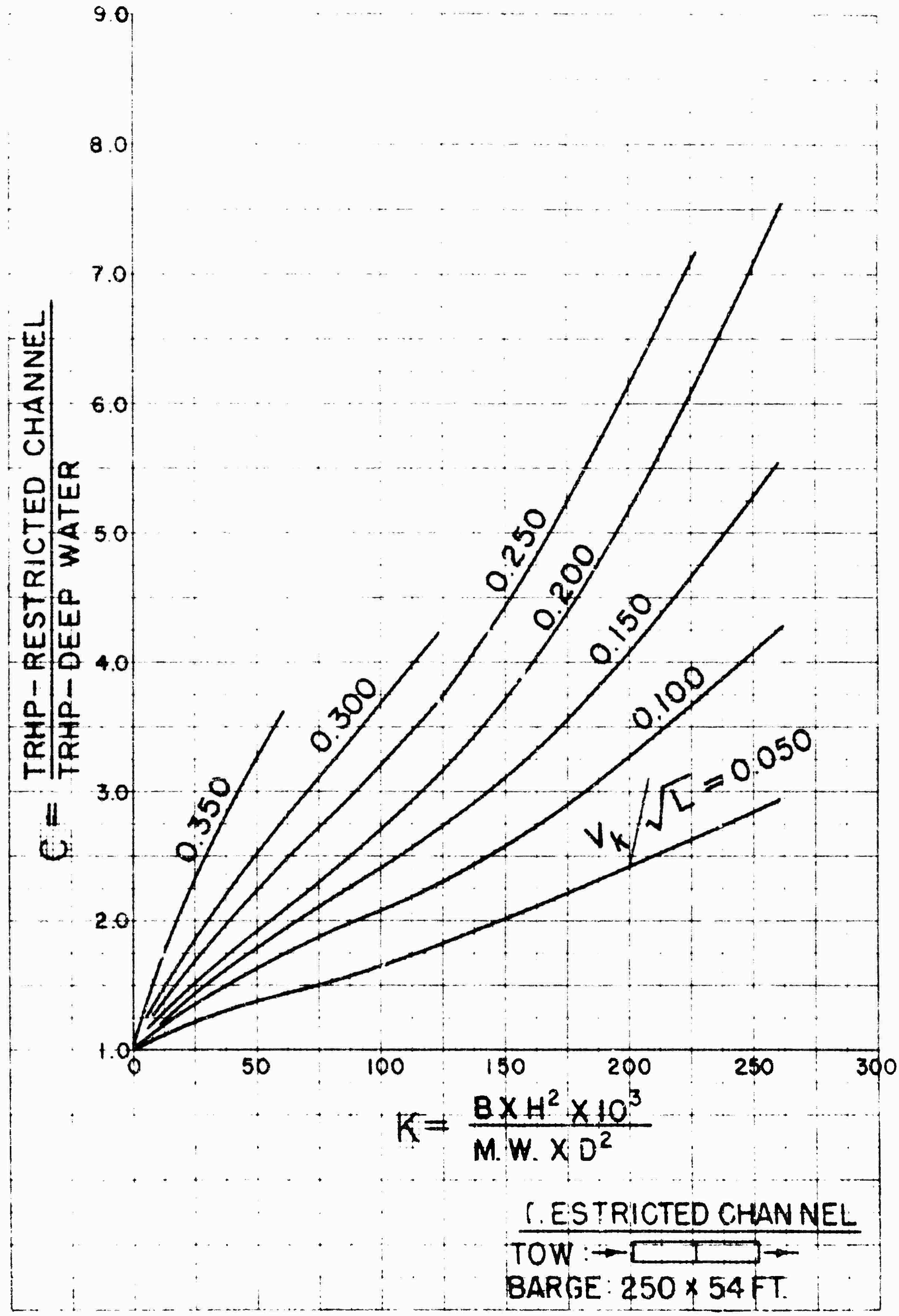
PLATE 74



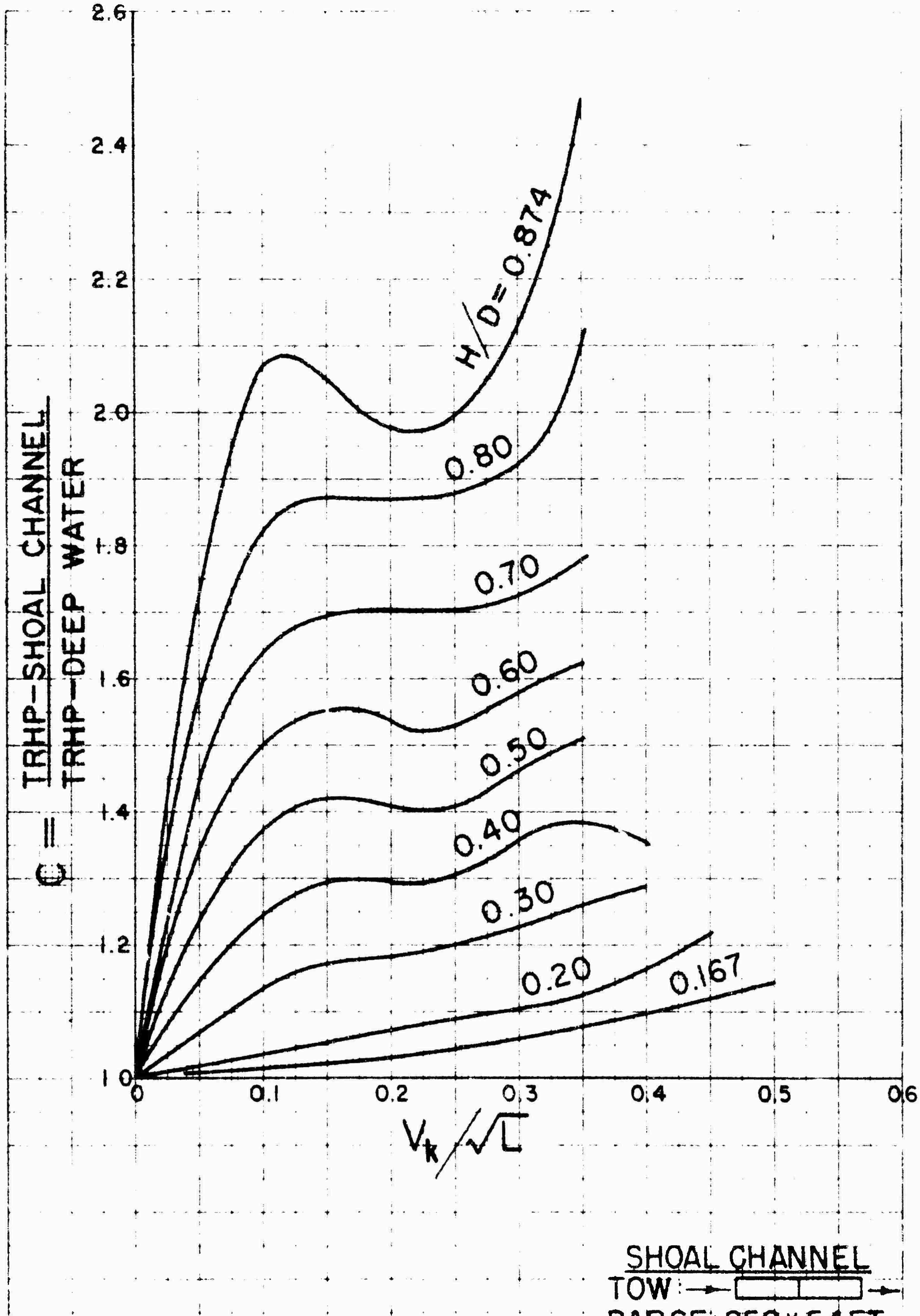
DRAFTS
3.0 FT.
14.0 FT.
SPEED
T-M/HR
DRAFT 3.0 FT
5.0
7.0
9.0
11.0
13.0
14.0
TOW
BARGE 250 x 54 FT.
SPEED - MPH
1000 T-M/HR
$V_k/\sqrt{L}$
0.50
0.40
0.30
0.20
0.10
0
10
20
30
40
50
60
70
80
90
1
2
3
4
5
6
7
8
9

PLATE 75

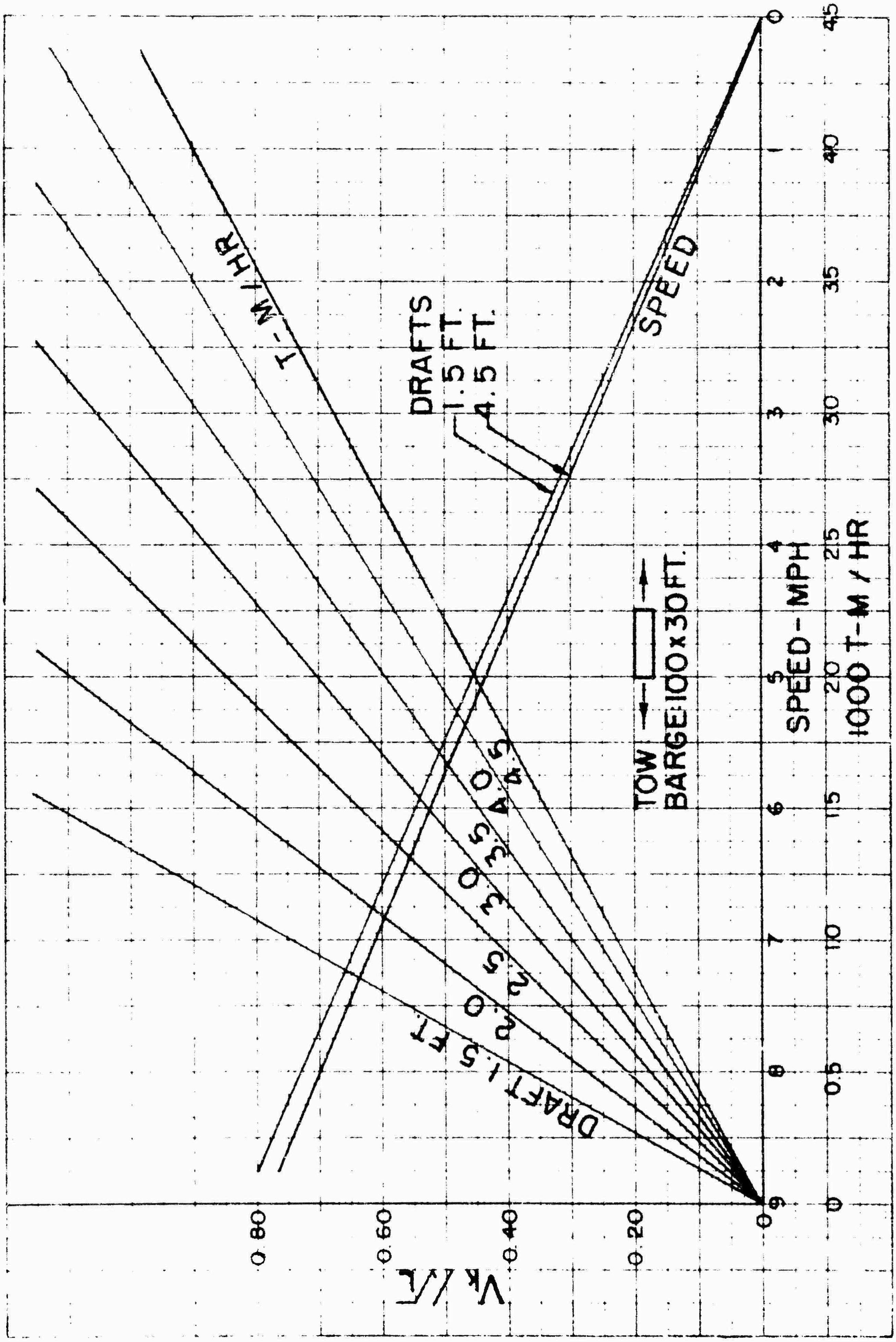

1000
100
10
T.R.H.P. - DEEP WATER
DRAFTS
14 ft.
13
11
9
7
5
3
TEST RESULTS SHOWN ON PLATES 18-20
TOW:
BARGE: 250×54 FT.
$V_K/\sqrt{L}$
0.1
0.2
0.3
0.4



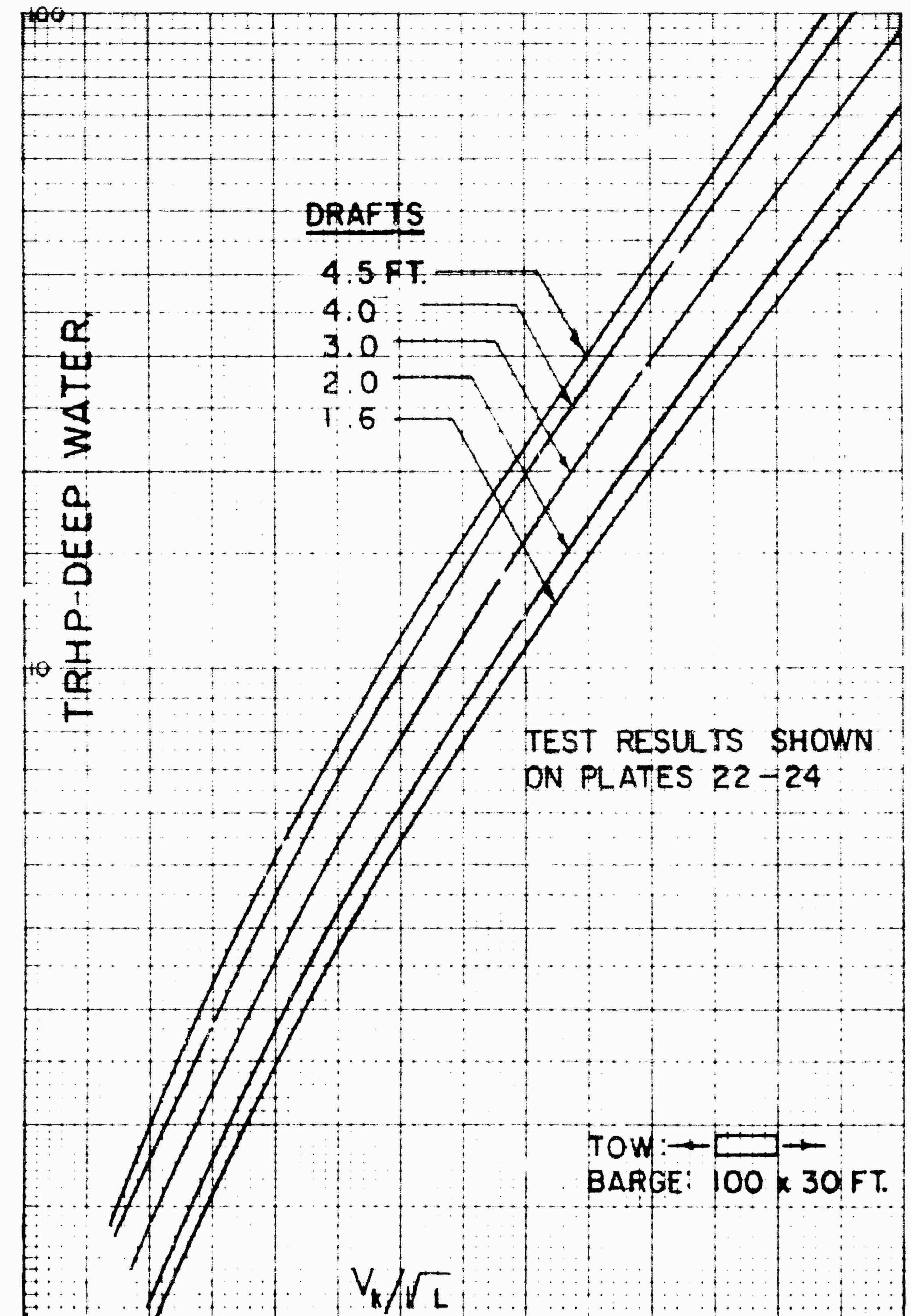
C = TRHP- RESTRICTED CHANNEL / TRHP- DEEP WATER
K = B X H² X 10³ / M.W. X D²
0 50 100 150 200 250 300
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0
0.350
0.300
0.250
0.200
0.150
0.100
Vk/√L = 0.050
RESTRICTED CHANNEL
TOW :
BARGE: 250 x 54 FT.

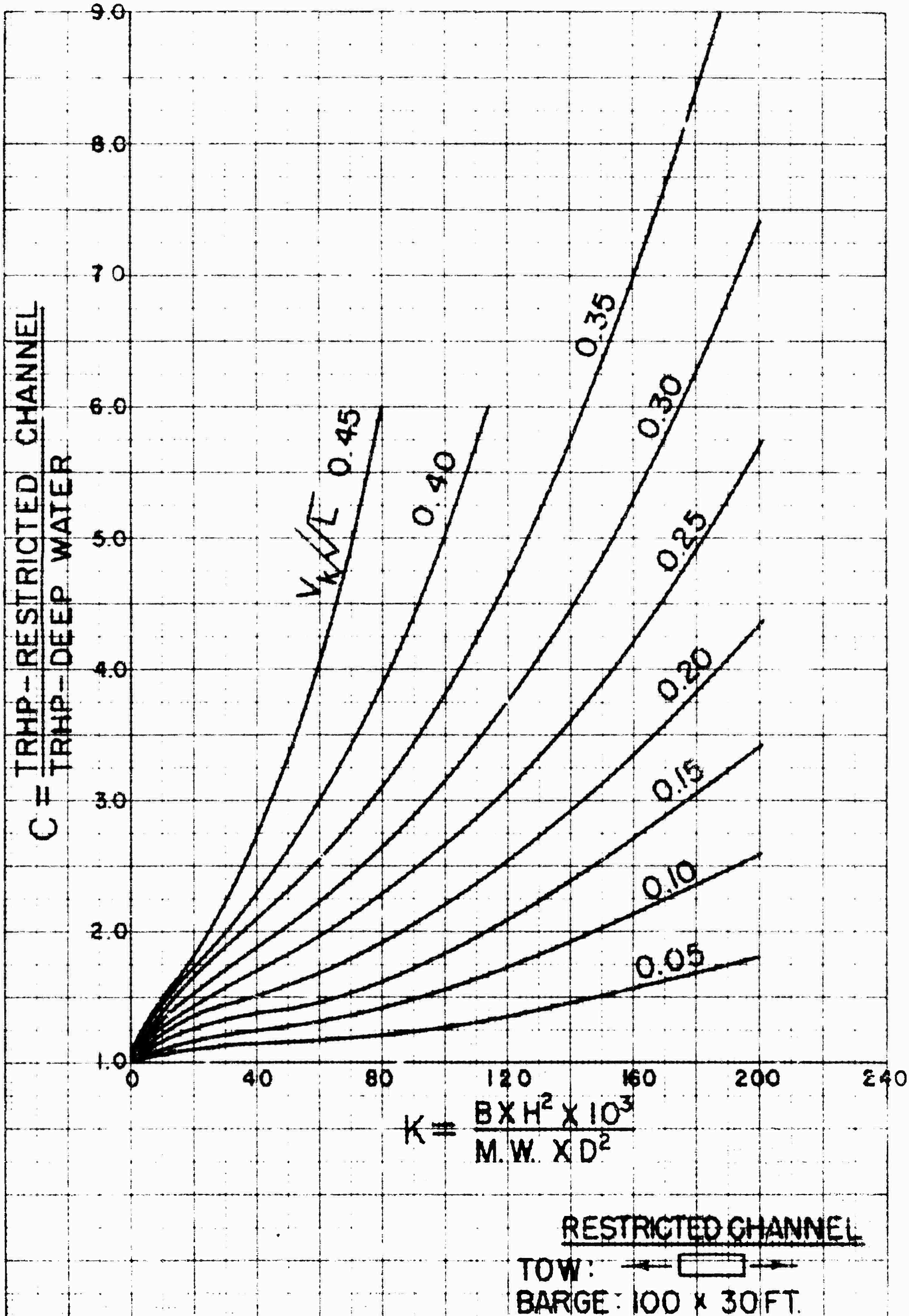


2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
0.1
0.2
0.3
0.4
0.5
0.6
C = TRHP-SHOAL CHANNEL / TRHP-DEEP WATER
Vk/√L
H/D = 0.874
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.167
SHOAL CHANNEL
TOW:
BARGE: 250×54FT.



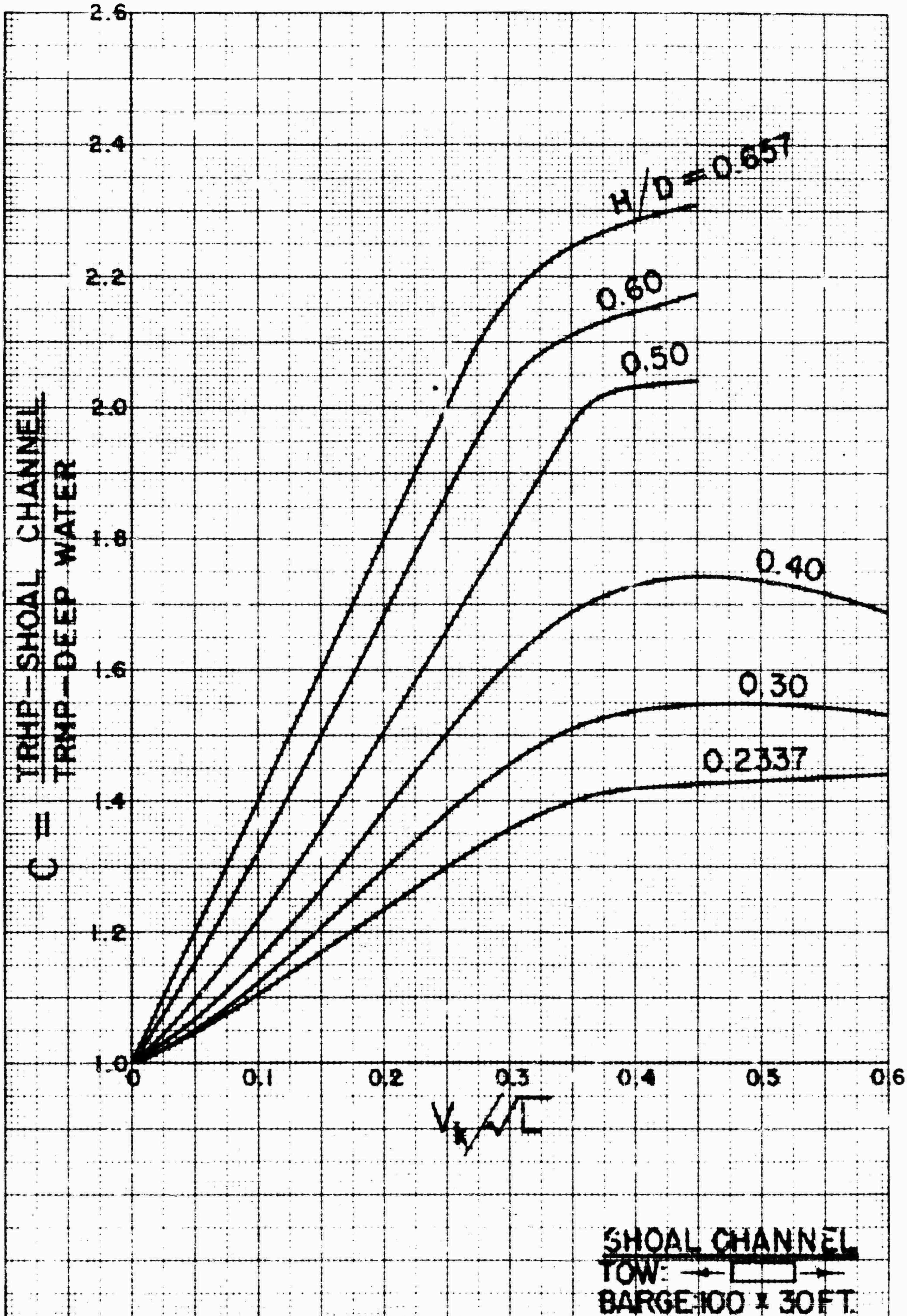
T-M / HR
SPEED
DRAFTS
1.5 FT.
4.5 FT.
DRAFT 1.5 FT.
2.0
2.5
3.0
3.5
4.0
4.5
TOW
BARGE 100x30FT.
SPEED - MPH
1000 T-M / HR
$V_k / \sqrt{L}$
0.80
0.60
0.40
0.20
0


100
10
TRHP-DEEP WATER
DRAFTS
4.5 FT.
4.0
3.0
2.0
1.6
TEST RESULTS SHOWN ON PLATES 22-24
TOW:
BARGE: 100 x 30 FT.
$V_k/\sqrt{L}$
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

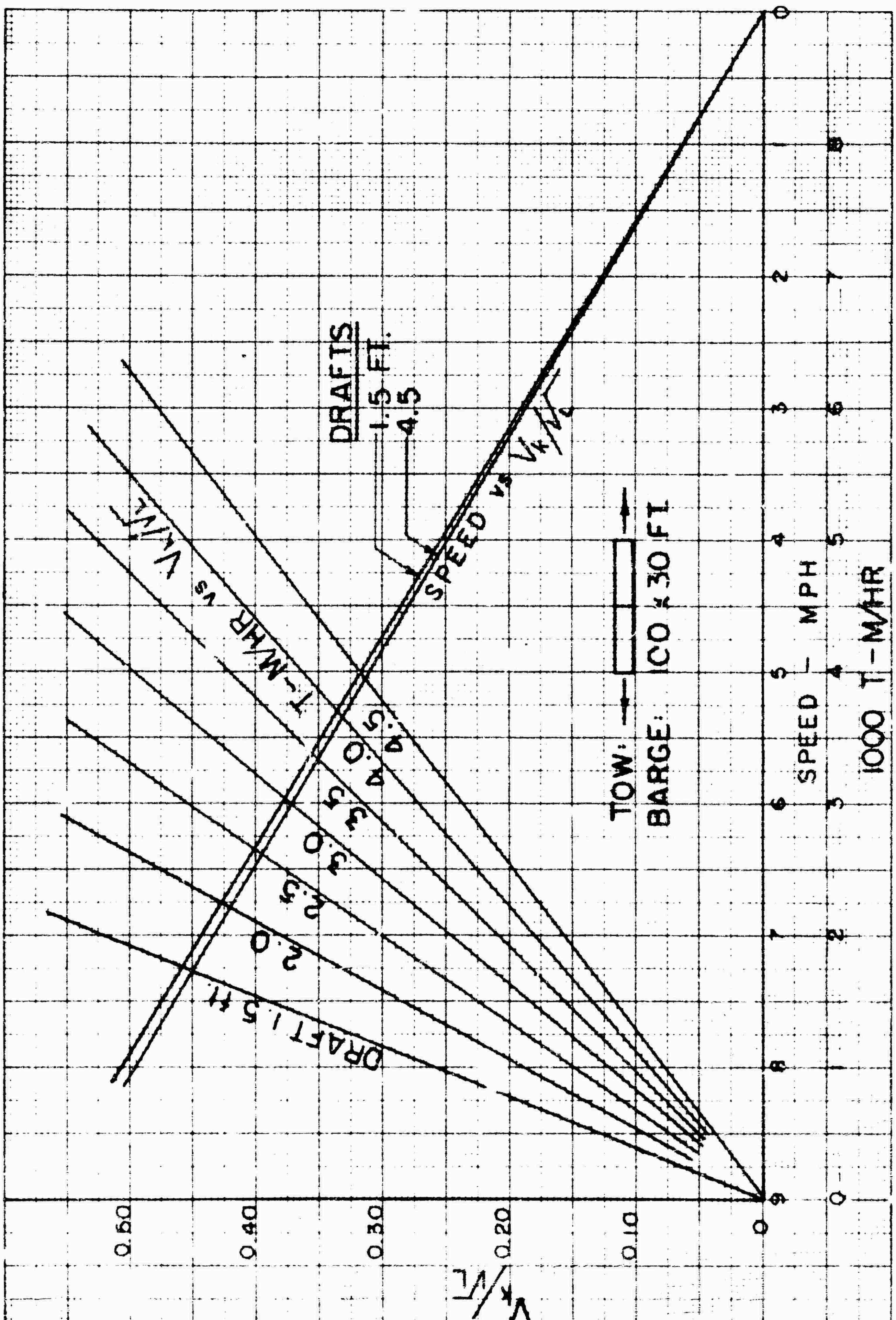


$C = \frac{\text{TRHP - RESTRICTED CHANNEL}}{\text{TRHP - DEEP WATER}}$
$K = \frac{B \times H^2 \times 10^3}{M.W. \times D^2}$
$V_K/\sqrt{L}$
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
0
40
80
120
160
200
240
RESTRICTED CHANNEL
TOW:
BARGE: 100 x 30 FT.

PLATE



2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
C = TRHP—SHOAL CHANNEL / TRHP—DEEP WATER
H/D = 0.657
0.60
0.50
0.40
0.30
0.2337
0
0.1
0.2
0.3
0.4
0.5
0.6
SHOAL CHANNEL
TOW:
BARGE:100 × 30FT.


DRAFTS
1.5 FT.
4.5
SPEED vs $V_k/\sqrt{L}$
T-M/HR vs $V_k/\sqrt{L}$
TOW:
BARGE: 100 x 30 FT
SPEED — MPH
1000 T-M/HR
DRAFT 1.5 ft
2.0
2.5
3.0
3.5
4.0
4.5
$V_k/\sqrt{L}$
0.50
0.40
0.30
0.20
0.10
0

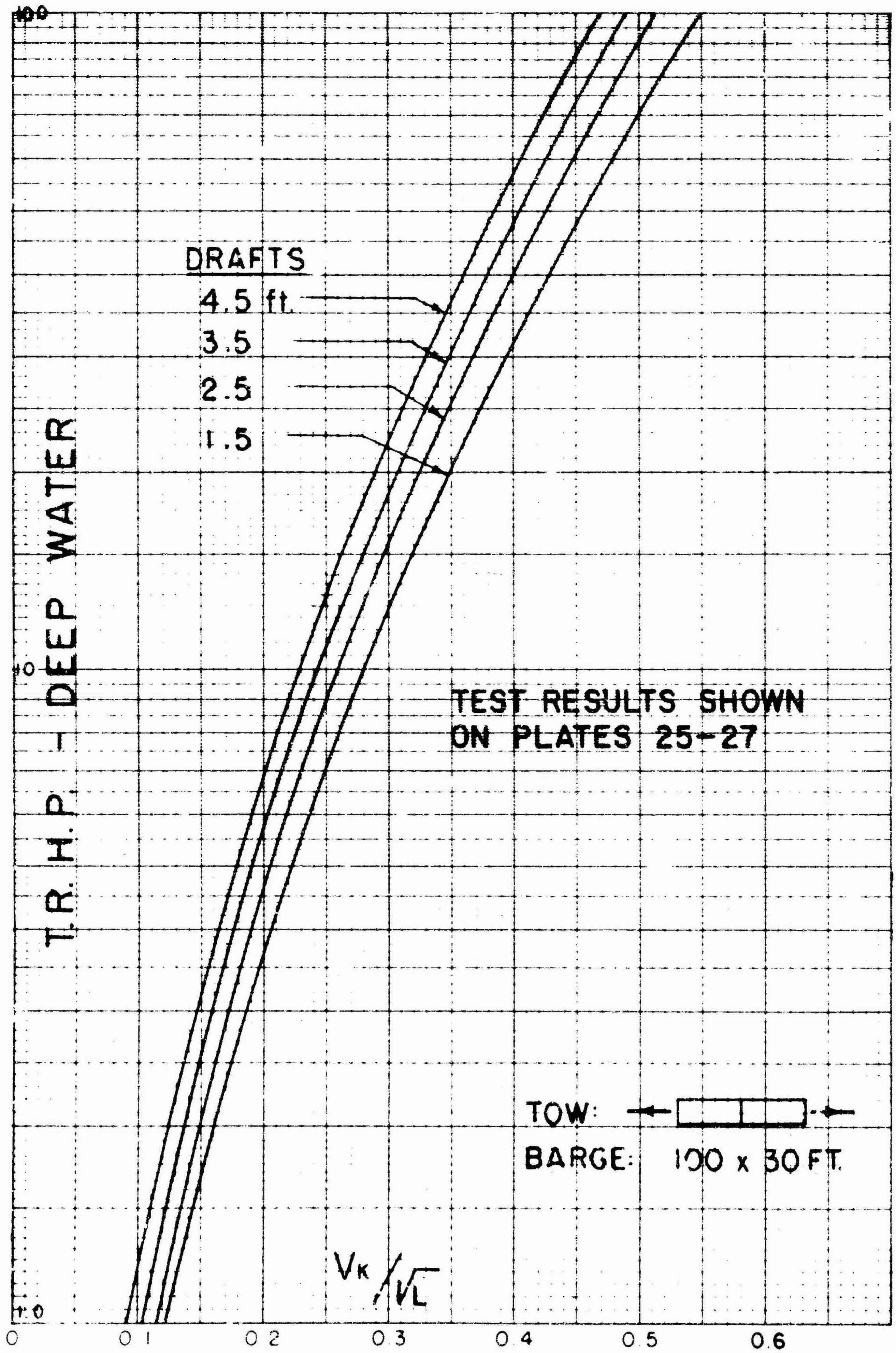
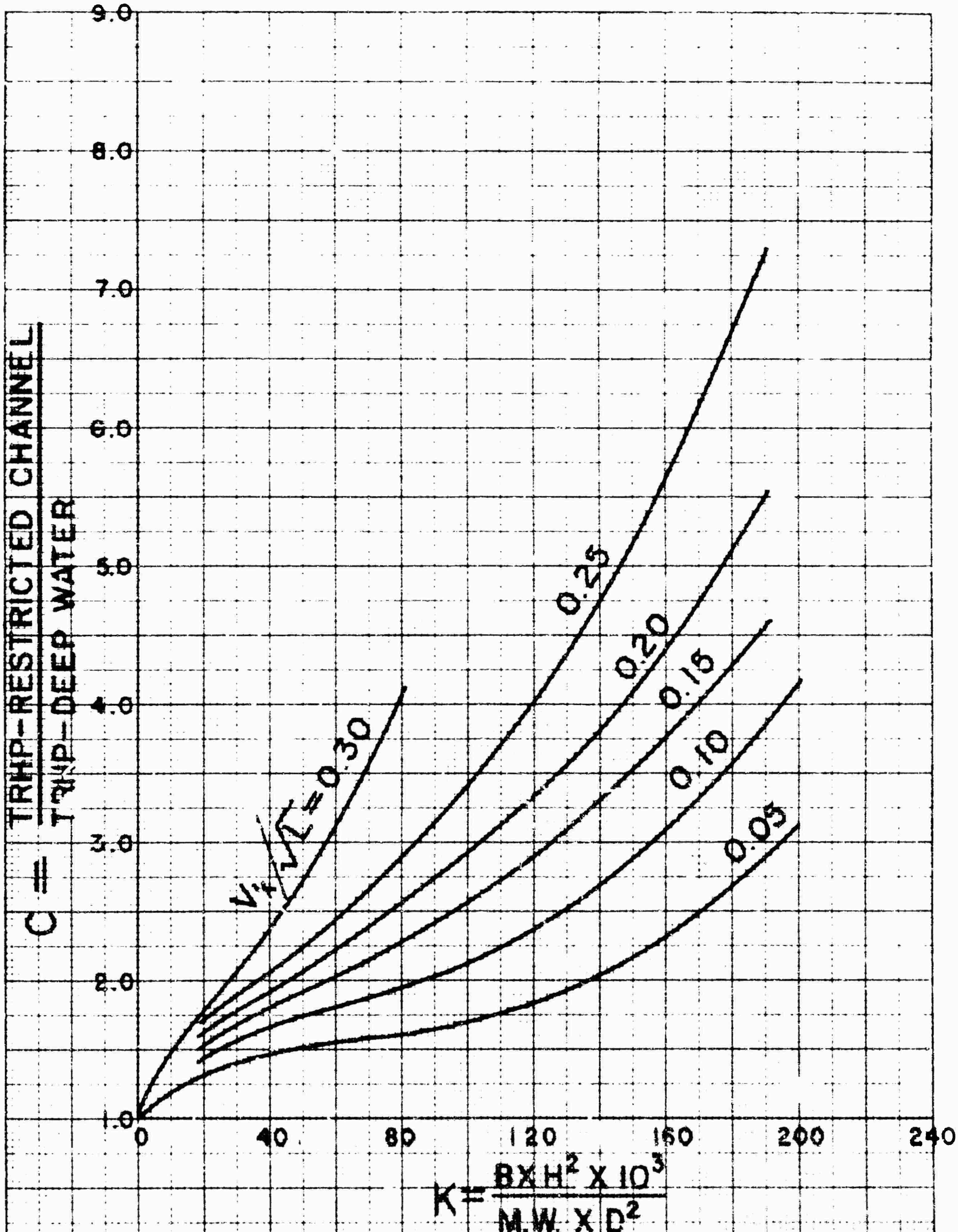
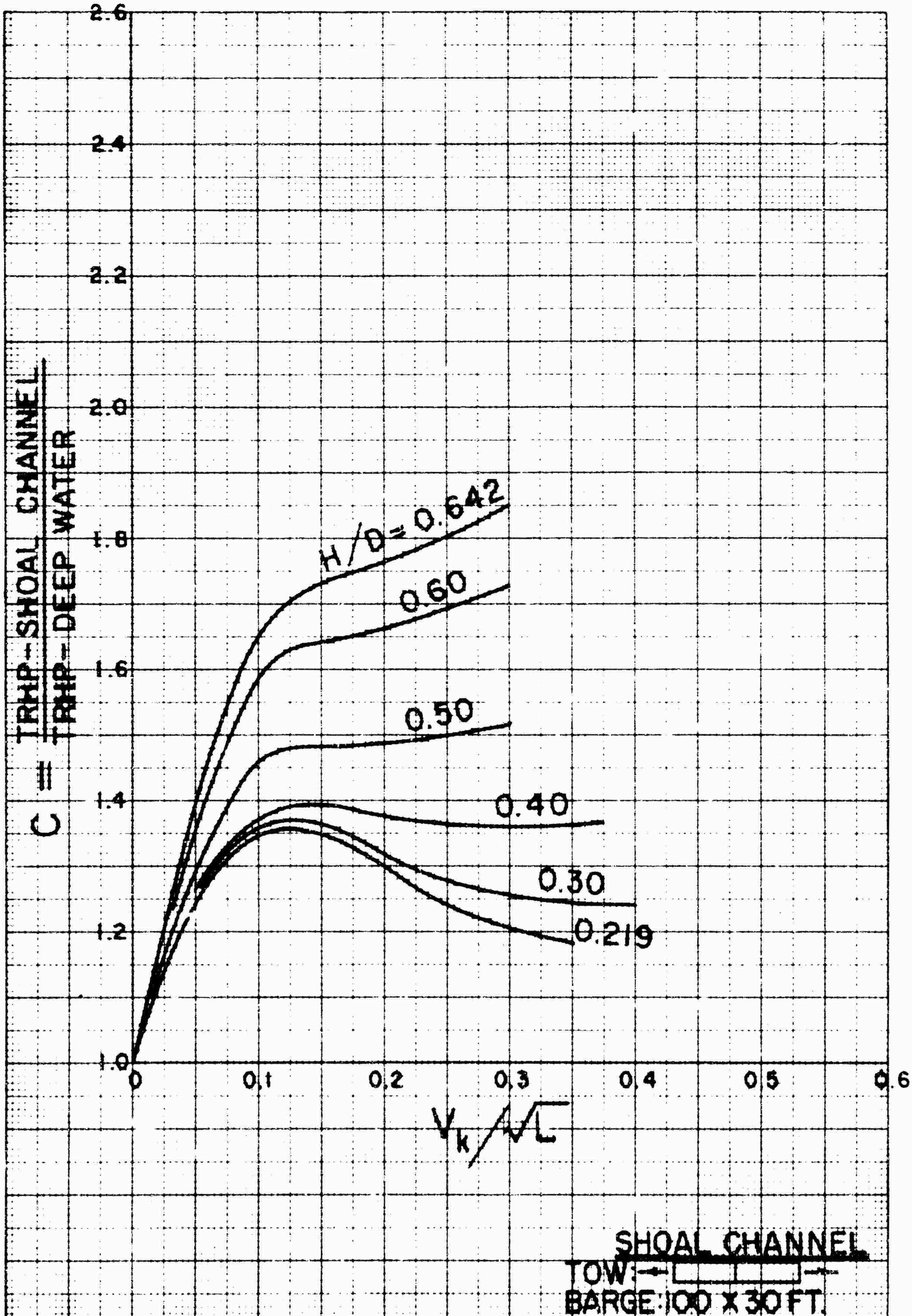

100
10
1.0
T.R. H.P. - DEEP WATER
DRAFTS
4.5 ft.
3.5
2.5
1.5
TEST RESULTS SHOWN
ON PLATES 25-27
TOW:
BARGE: 100 x 30 FT.
$V_K / \sqrt{L}$
0
0.1
0.2
0.3
0.4
0.5
0.6

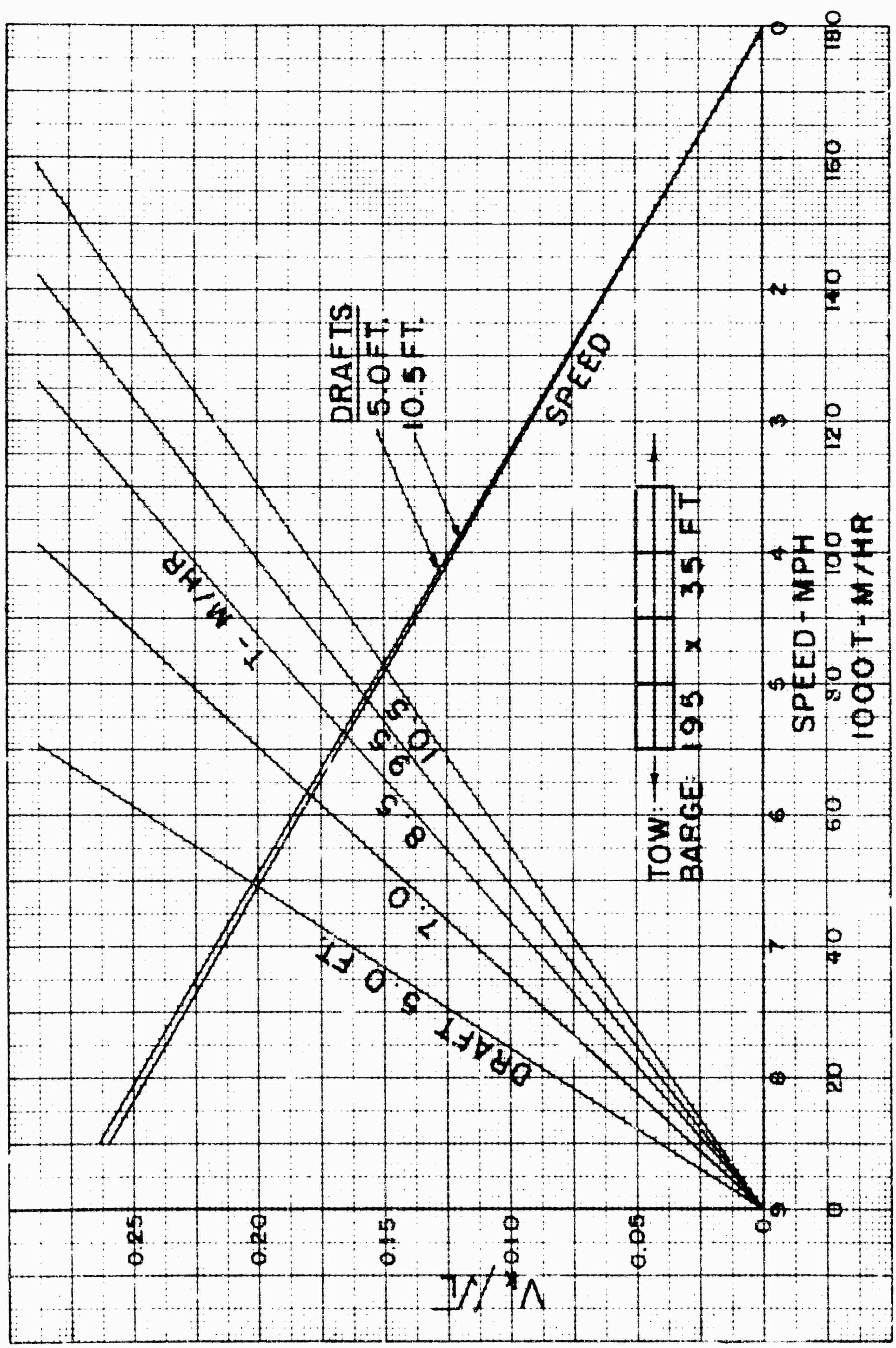
PLATE 24



9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
40
80
120
160
200
240
C = TRHP-RESTRICTED CHANNEL / TRHP-DEEP WATER
$V_t/\sqrt{L}$ = 0.30
0.25
0.20
0.15
0.10
0.05
$K = \frac{B \times H^2 \times 10^3}{M.W. \times D^2}$
RESTRICTED CHANNEL
TOW:
BARGE: 100×30FT.

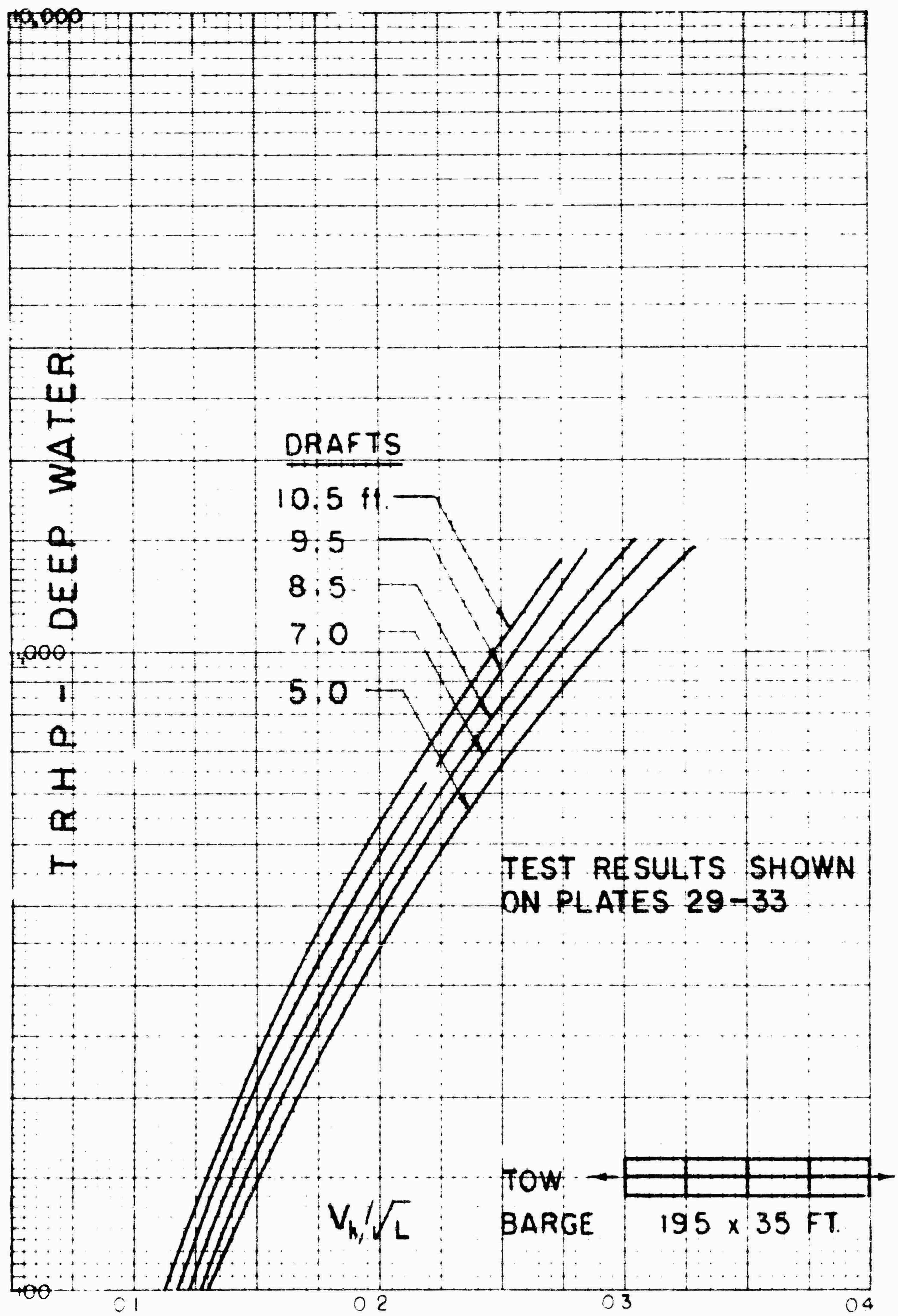


$C = \frac{\text{TRHP - SHOAL CHANNEL}}{\text{TRHP - DEEP WATER}}$
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
0.1
0.2
0.3
0.4
0.5
0.6
$V_k/\sqrt{L}$
H/D = 0.642
0.60
0.50
0.40
0.30
0.219
SHOAL CHANNEL
TOW:
BARGE: 100 X 30 FT.

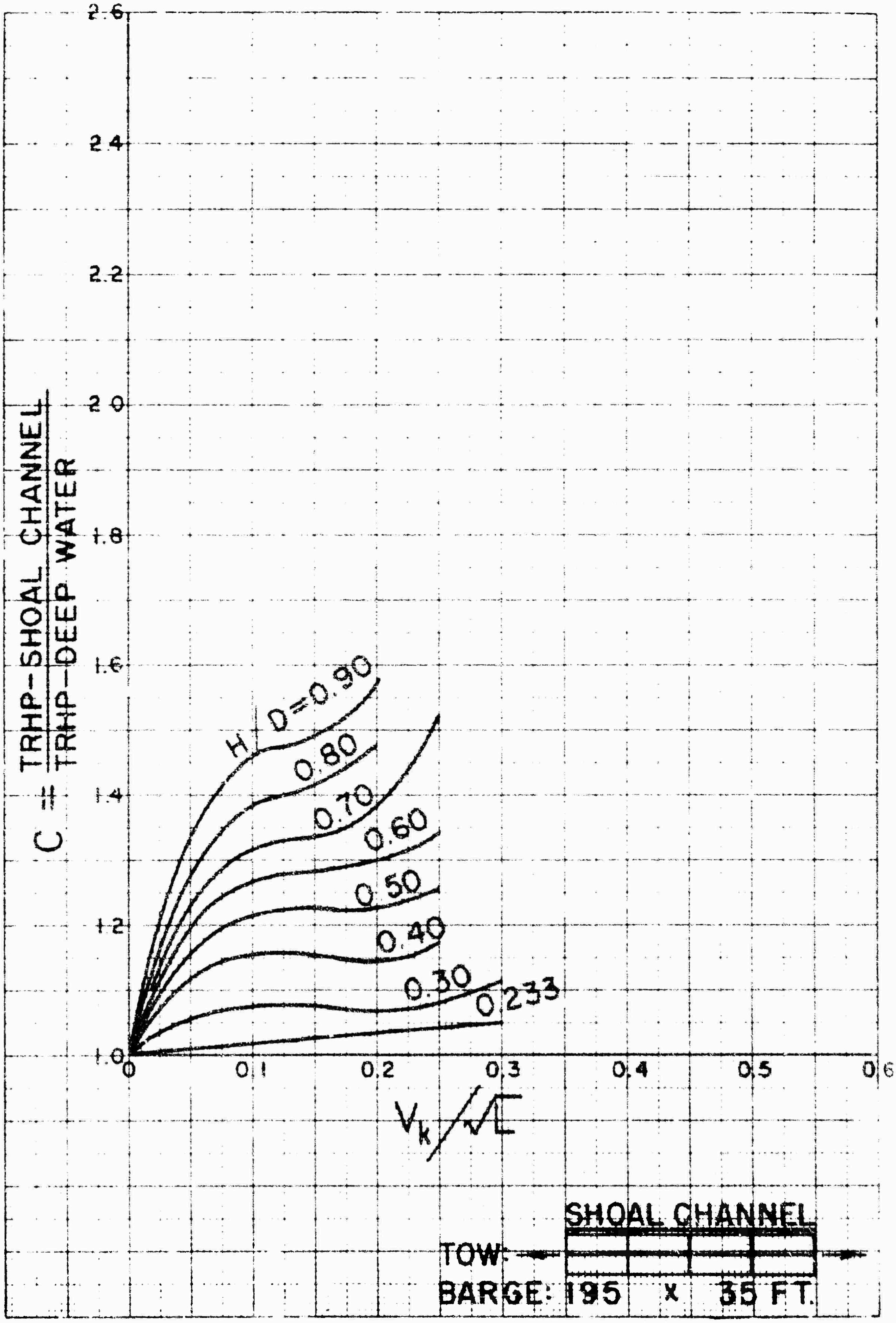


DRAFTS
5.0 FT.
10.5 FT.
SPEED
T-M/HR
DRAFT 5.0 FT
7.0
8.5
9.5
10.5
TOW:
BARGE: 195 x 35 FT
SPEED-MPH
1000 T-M/HR
$V_*/\sqrt{L}$
0
0.05
0.10
0.15
0.20
0.25
0
1
2
3
4
5
6
7
8
9
20
40
60
80
100
120
140
160
180

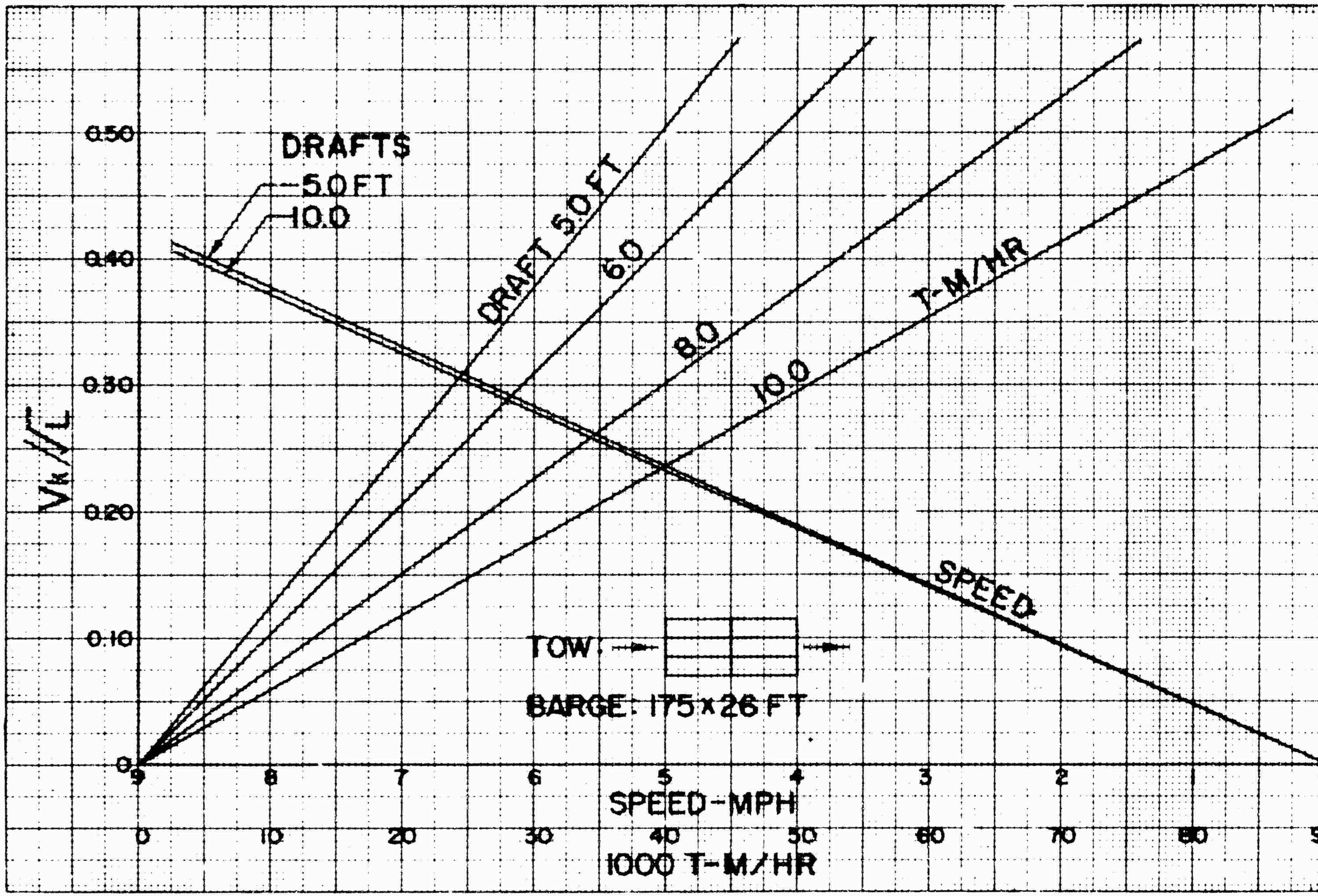
PLATE 87



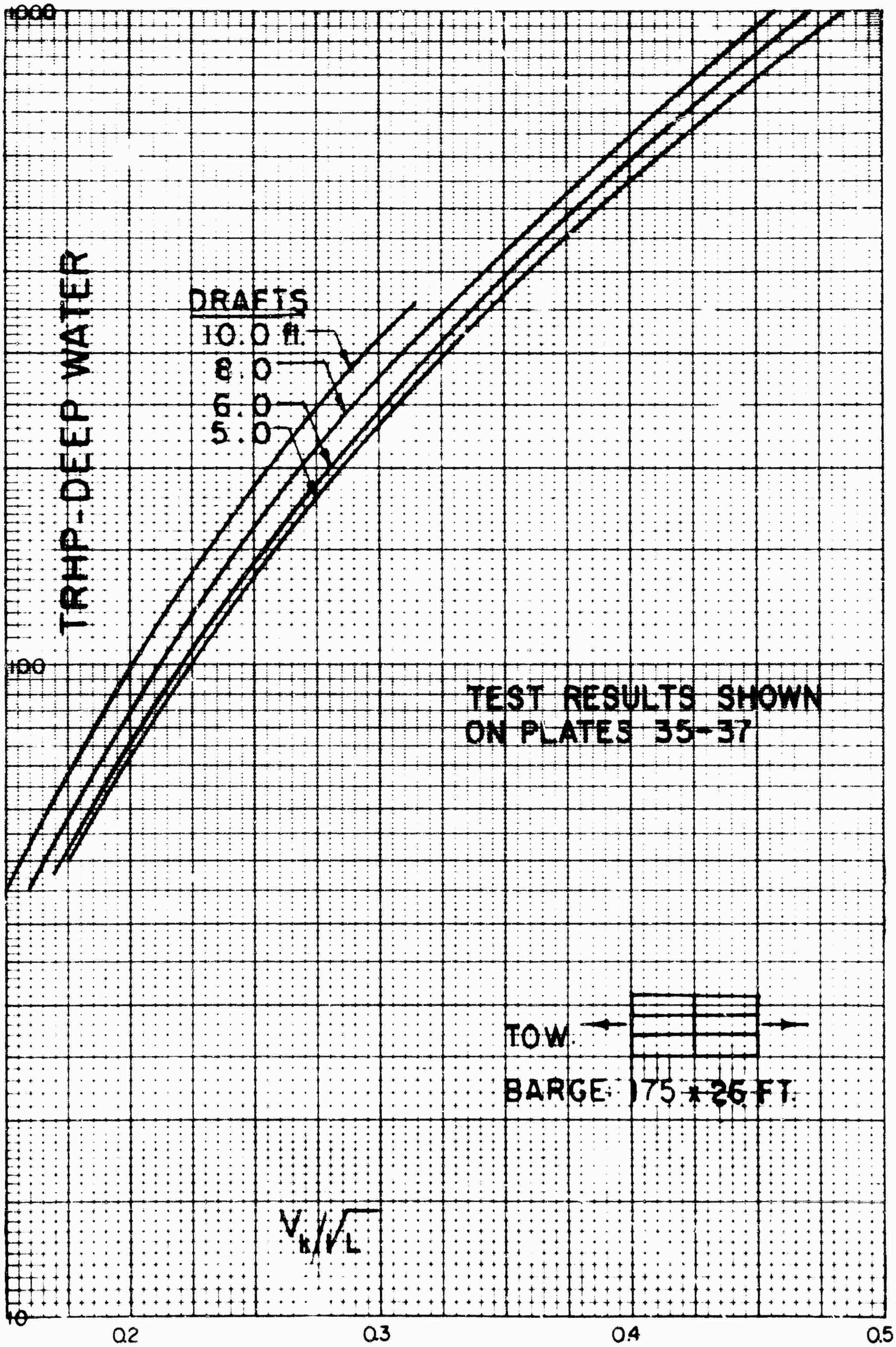
10,000
1,000
100
T R H P - DEEP WATER
DRAFTS
10.5 ft.
9.5
8.5
7.0
5.0
TEST RESULTS SHOWN
ON PLATES 29-33
TOW
BARGE
195 x 35 FT.
$V_h/\sqrt{L}$
0.1
0.2
0.3
0.4

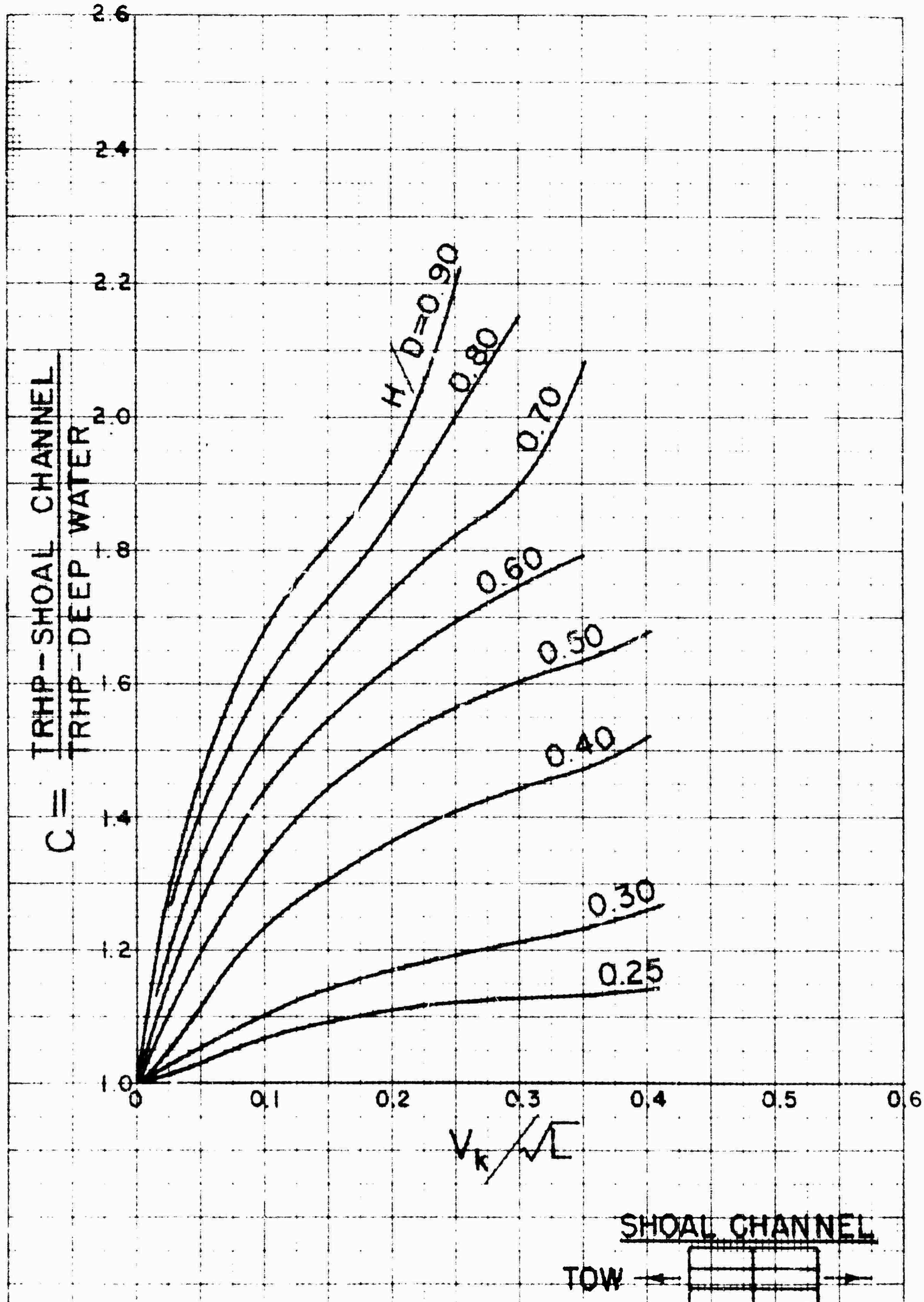


2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
C = TRHP-SHOAL CHANNEL / TRHP-DEEP WATER
H/D=0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.233
0
0.1
0.2
0.3
0.4
0.5
0.6
$V_k/\sqrt{L}$
SHOAL CHANNEL
TOW:
BARGE: 195 x 35 FT.

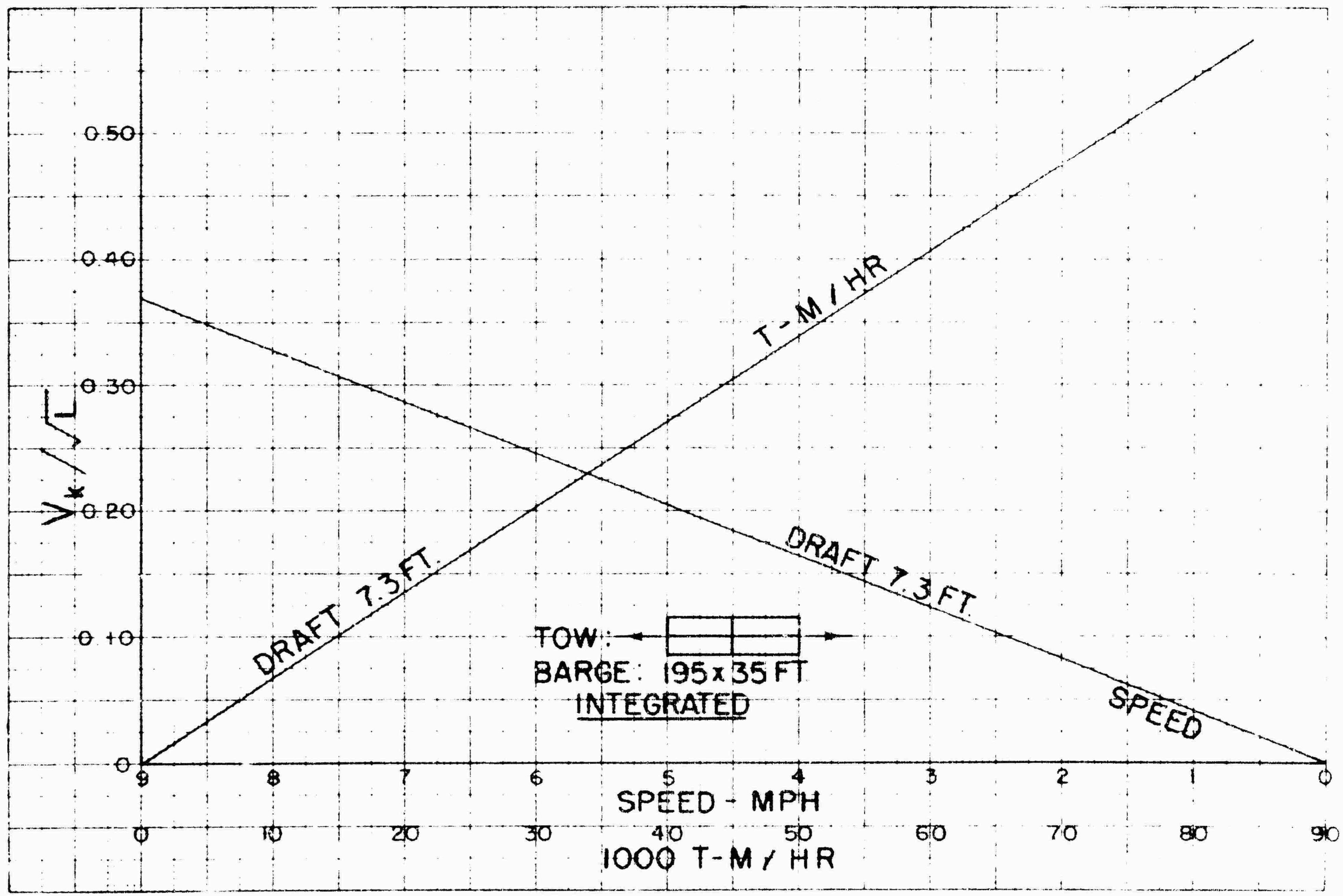


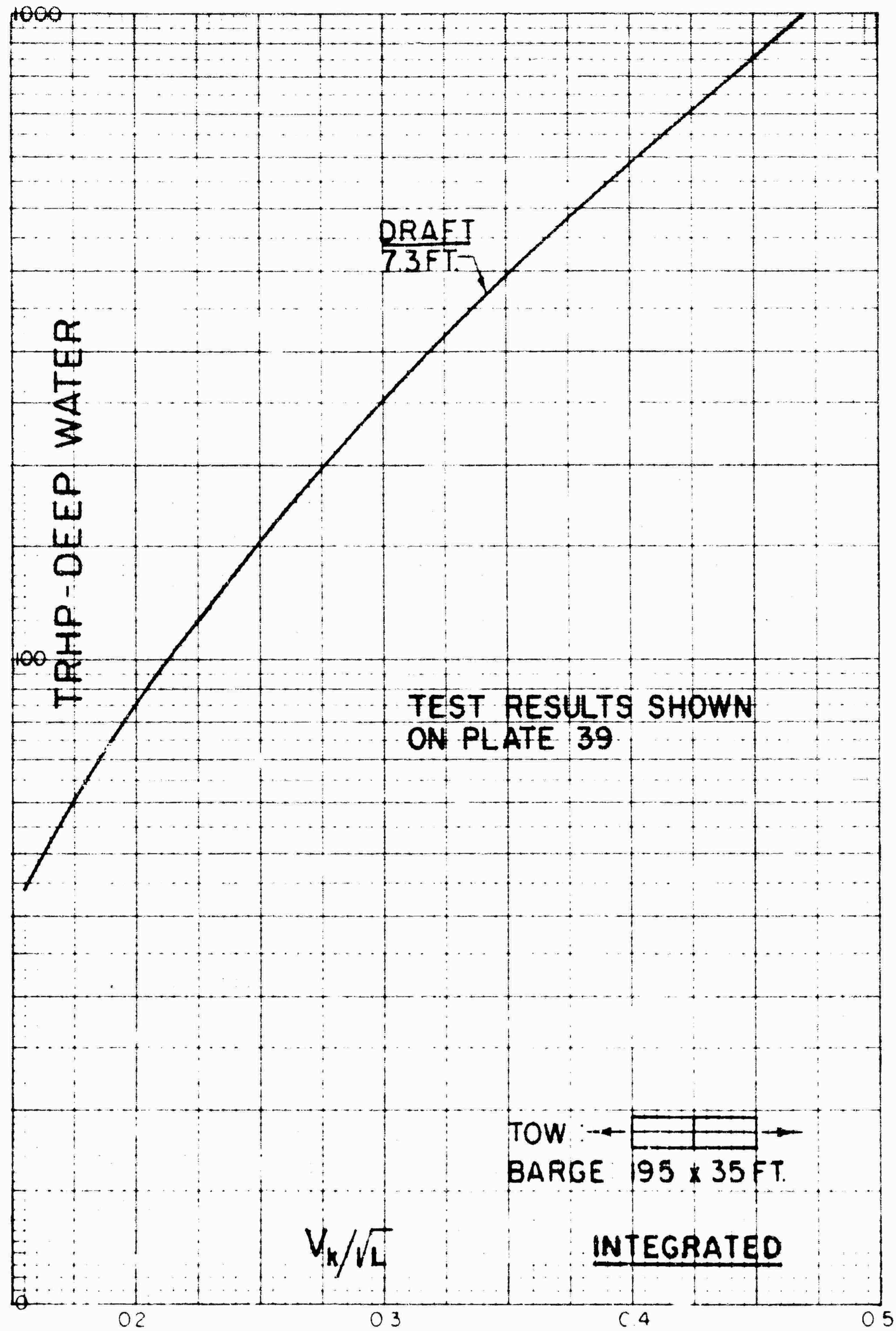
DRAFTS
5.0 FT
10.0
DRAFT 5.0 FT
6.0
8.0
10.0
T-M/HR
SPEED
TOW:
BARGE: 175 x 26 FT
$V_k/\sqrt{L}$
0.50
0.40
0.30
0.20
0.10
0
9
8
7
6
5
4
3
2
1
0
SPEED-MPH
0
10
20
30
40
50
60
70
80
90
1000 T-M/HR


TRHP-DEEP WATER
DRAFTS
10.0 ft.
8.0
6.0
5.0
1000
100
10
TEST RESULTS SHOWN ON PLATES 35-37
TOW
BARGE 175 x 26 FT.
$V_k/\sqrt{L}$
0.2
0.3
0.4
0.5

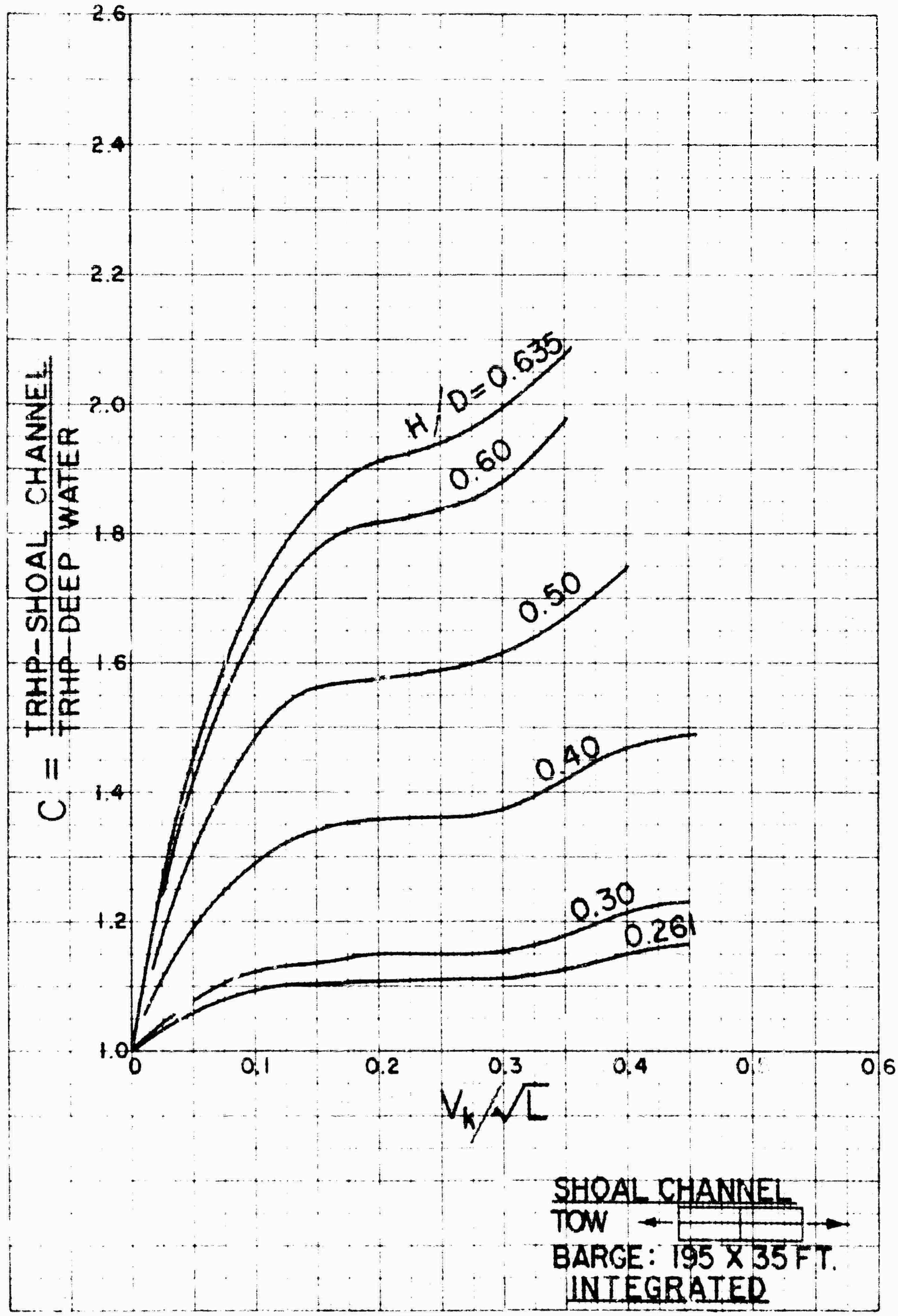


C = TRHP-SHOAL CHANNEL / TRHP-DEEP WATER
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
0.1
0.2
0.3
0.4
0.5
0.6
$V_k/\sqrt{L}$
H/D=0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.25
SHOAL CHANNEL
TOW
BARGE 175 X 26 FT.

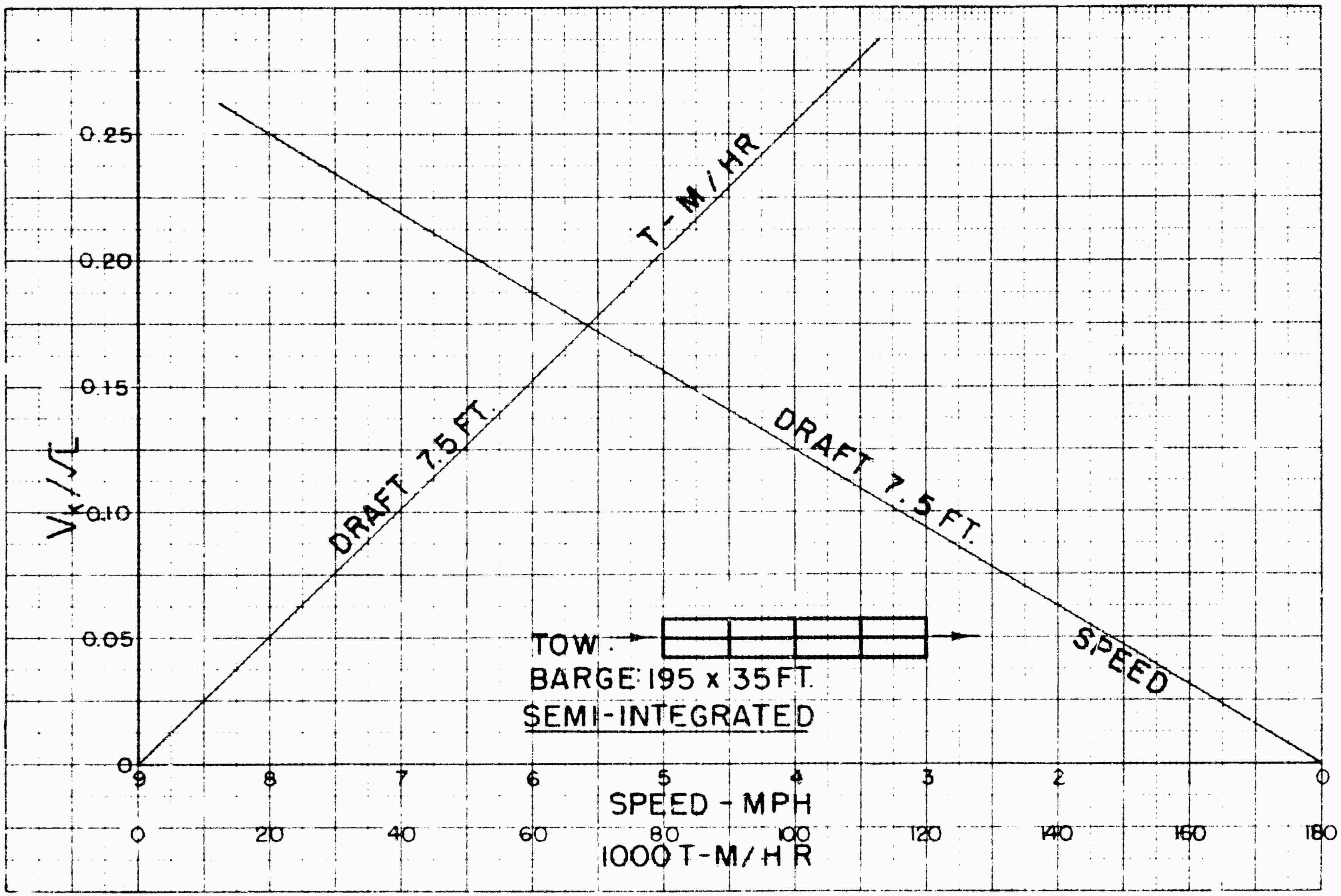

$V_k/\sqrt{L}$
0.50
0.40
0.30
0.20
0.10
0
T-M / HR
DRAFT 7.3 FT.
DRAFT 7.3 FT.
SPEED
TOW:
BARGE: 195 x 35 FT
INTEGRATED
9 8 7 6 5 4 3 2 1 0
SPEED - MPH
0 10 20 30 40 50 60 70 80 90
1000 T-M / HR



1000
100
0
TRHP-DEEP WATER
DRAFT
7.3 FT.
TEST RESULTS SHOWN
ON PLATE 39
TOW
BARGE 195 x 35 FT.
$V_k/\sqrt{L}$
INTEGRATED
0.2
0.3
0.4
0.5

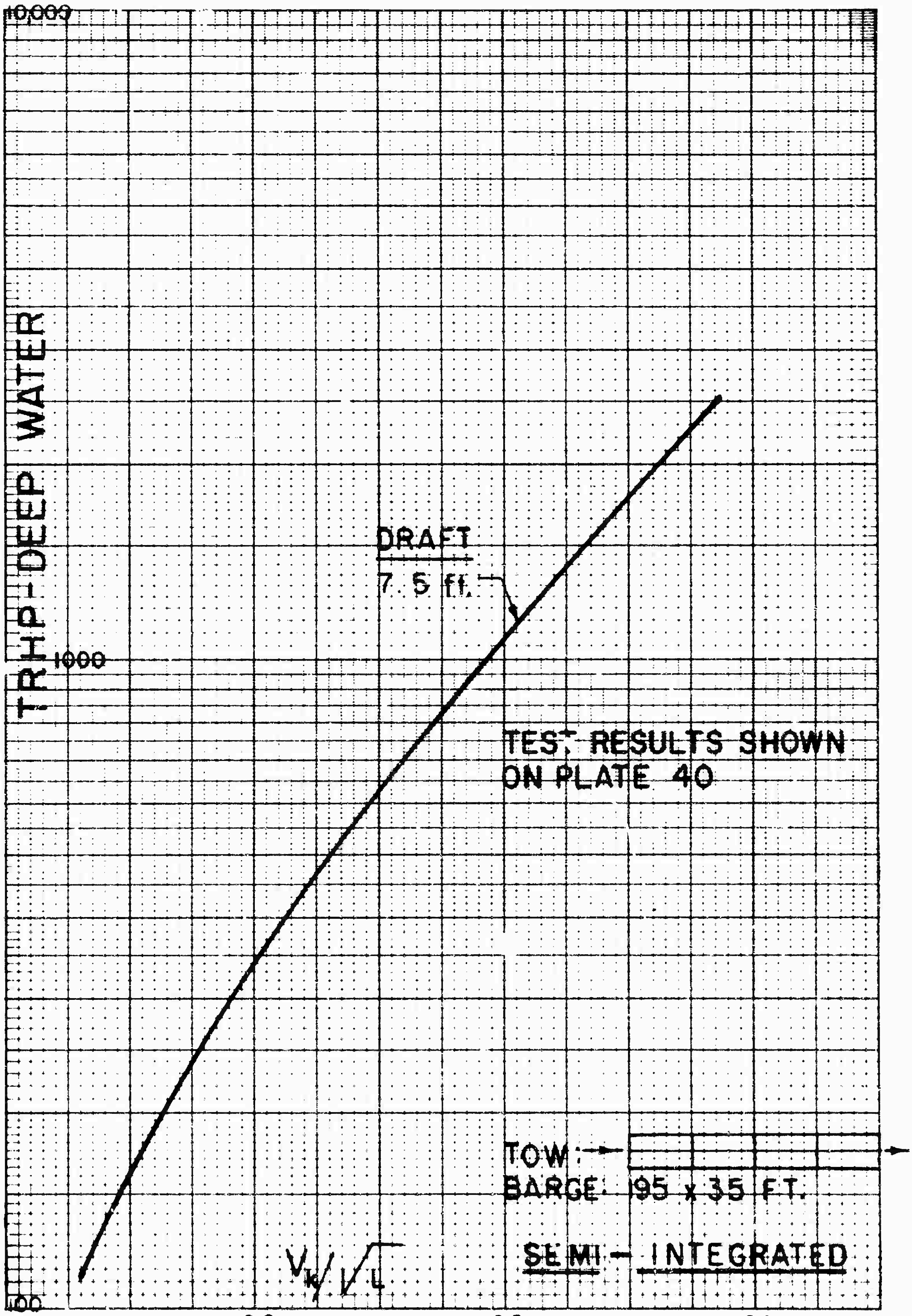


2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
0.1
0.2
0.3
0.4
0.6
C = TRHP-SHOAL CHANNEL / TRHP-DEEP WATER
H/D=0.635
0.60
0.50
0.40
0.30
0.261
Vk/√L
SHOAL CHANNEL
TOW
BARGE: 195 X 35 FT.
INTEGRATED

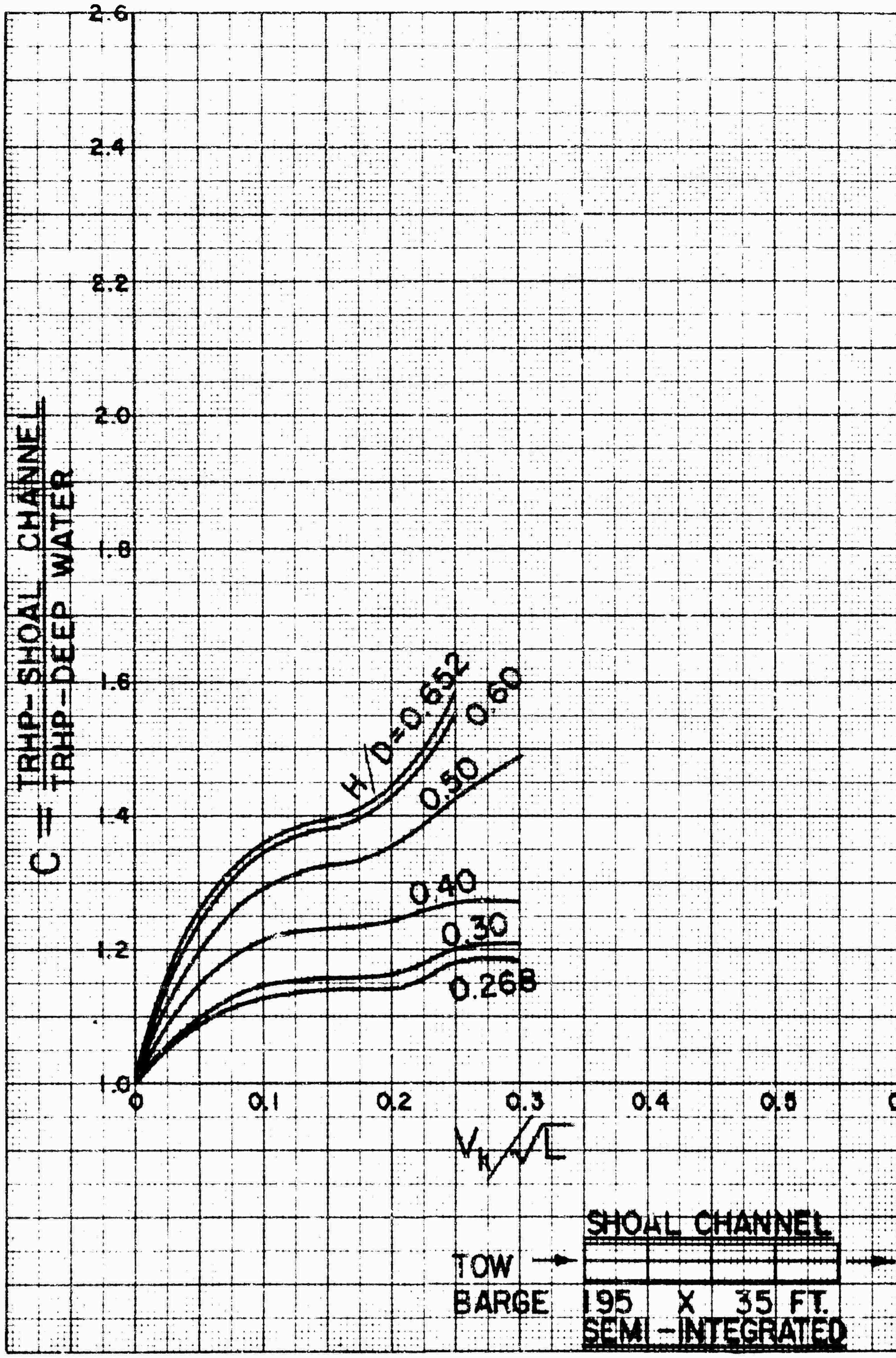


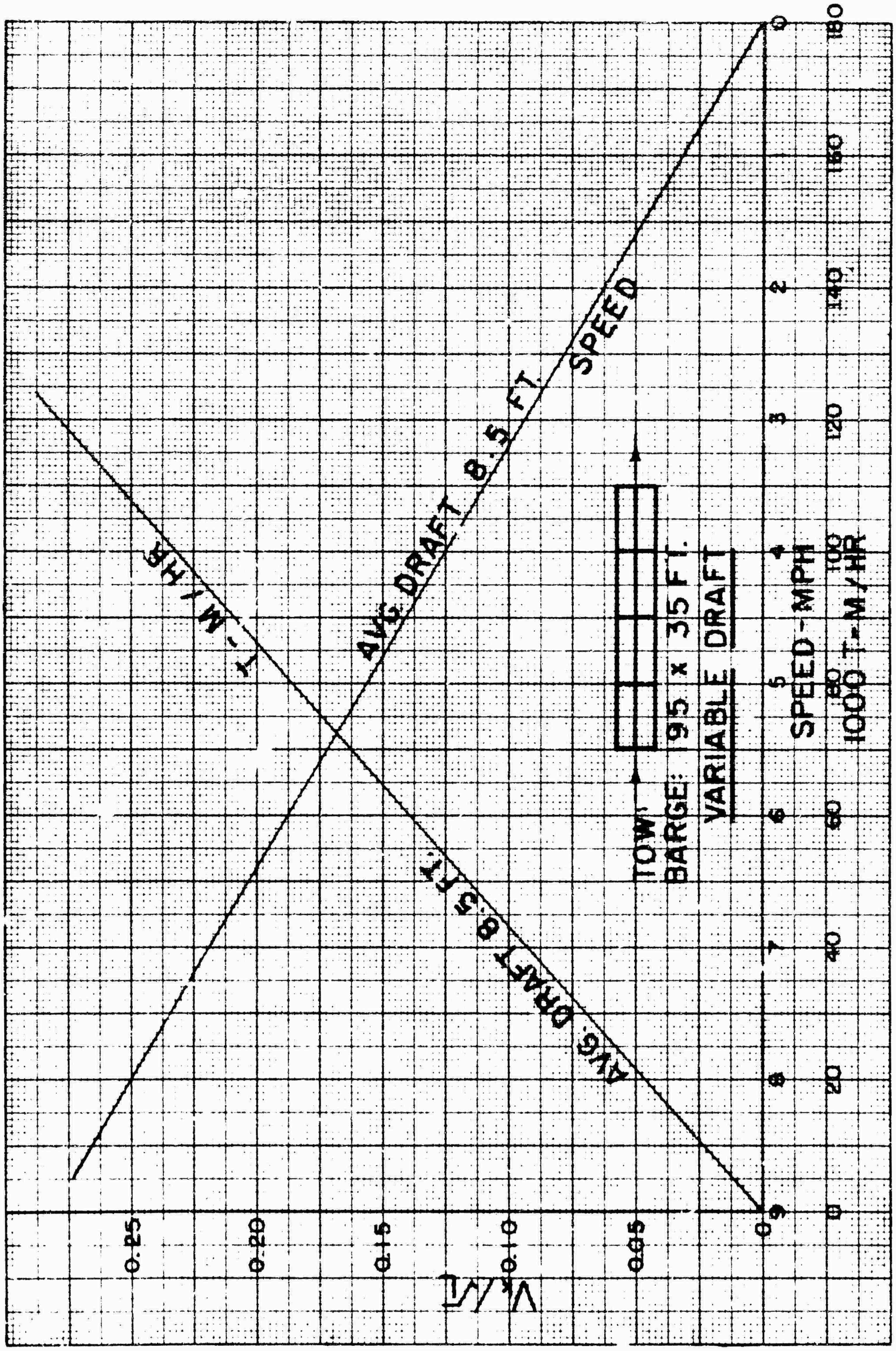
T-M/HR
DRAFT 7.5 FT.
DRAFT 7.5 FT.
SPEED
TOW
BARGE 195 x 35 FT.
SEMI-INTEGRATED
0.25
0.20
0.15
0.10
0.05
0
$V_k/\sqrt{L}$
9
8
7
6
5
4
3
2
0
SPEED - MPH
0
20
40
60
80
100
120
140
160
180
1000 T-M/HR

PLATE 96

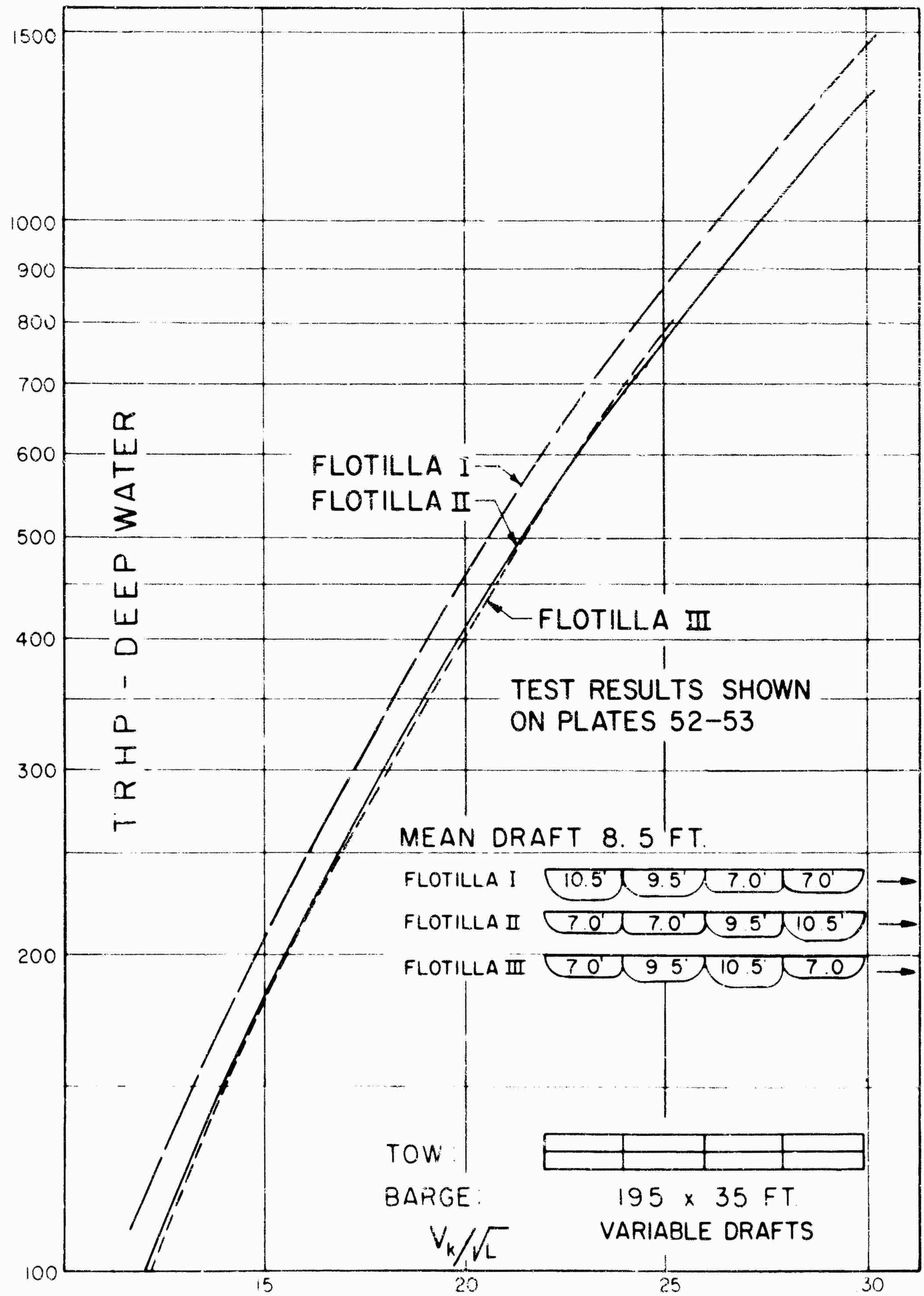


TRHP - DEEP WATER
10,000
1000
100
0.2
0.3
0.4
DRAFT
7.5 ft.
TEST RESULTS SHOWN
ON PLATE 40
TOW:
BARGE: 195 x 35 FT.
SEMI - INTEGRATED
$V_k / \sqrt{L}$

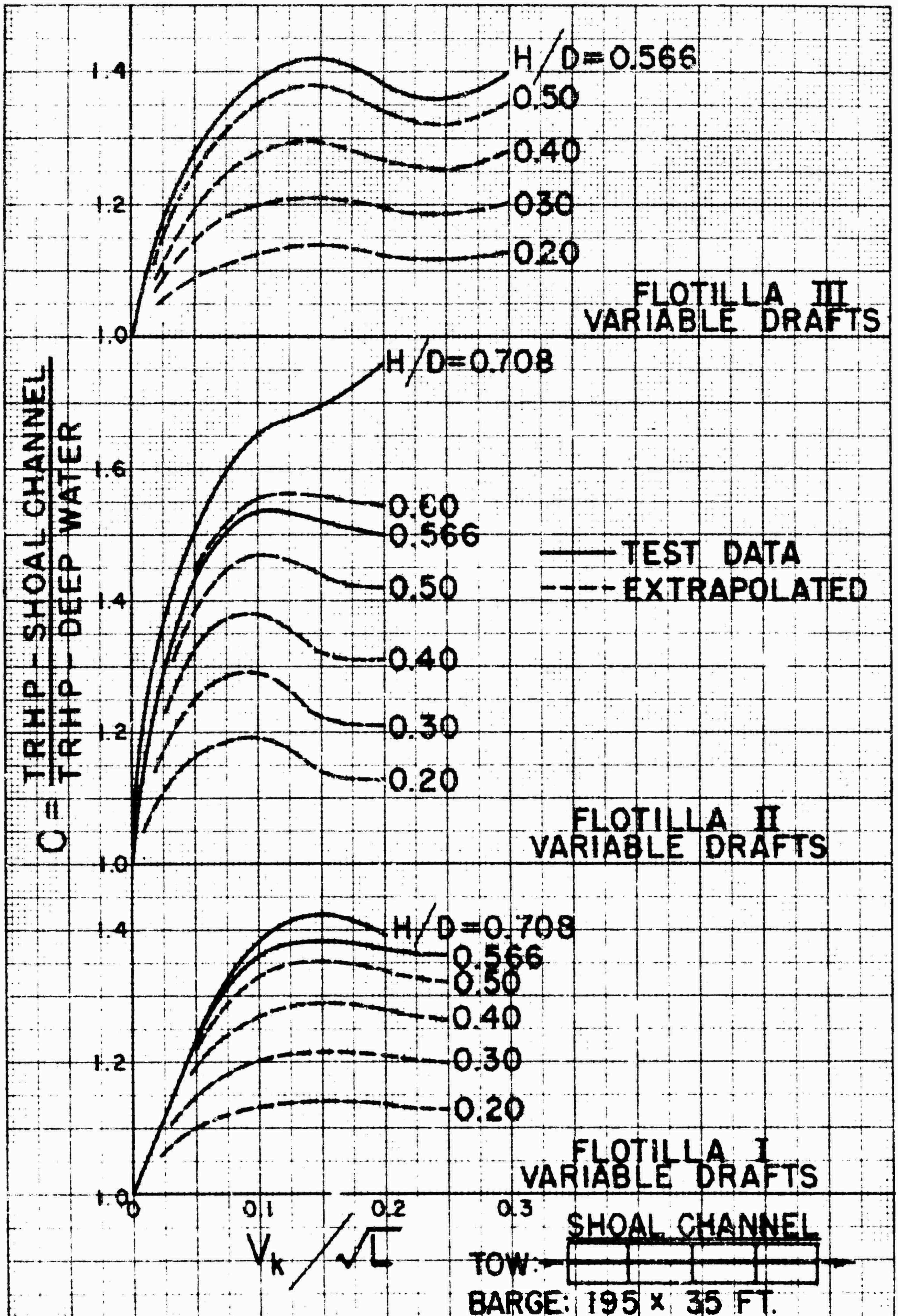

C = TRHP-SHOAL CHANNEL / TRHP-DEEP WATER
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
0.1
0.2
0.3
0.4
0.5
0.6
$V_K/\sqrt{L}$
H/D=0.652
0.60
0.50
0.40
0.30
0.268
SHOAL CHANNEL
TOW
BARGE 195 X 35 FT.
SEMI-INTEGRATED



AVG. DRAFT 8.5 FT. SPEED
AVG. DRAFT 8.5 FT. T-M/HR
TOW
BARGE: 195 x 35 FT.
VARIABLE DRAFT
SPEED - MPH
1000 T-M/HR



1500
1000
900
800
700
600
500
400
300
200
100
T R H P - DEEP WATER
FLOTILLA I
FLOTILLA II
FLOTILLA III
TEST RESULTS SHOWN ON PLATES 52-53
MEAN DRAFT 8. 5 FT.
FLOTILLA I 10.5' 9.5' 7.0' 7.0'
FLOTILLA II 7.0' 7.0' 9.5' 10.5'
FLOTILLA III 7.0' 9.5' 10.5' 7.0
TOW:
BARGE: 195 x 35 FT. VARIABLE DRAFTS
$V_k/\sqrt{L}$
15
20
25
30



H/D=0.566
0.50
0.40
0.30
0.20
FLOTILLA III
VARIABLE DRAFTS
H/D=0.708
0.60
0.566
0.50
0.40
0.30
0.20
TEST DATA
EXTRAPOLATED
FLOTILLA II
VARIABLE DRAFTS
H/D=0.708
0.566
0.50
0.40
0.30
0.20
FLOTILLA I
VARIABLE DRAFTS
C = TRHP - SHOAL CHANNEL / TRHP - DEEP WATER
1.0
1.2
1.4
1.6
0
0.1
0.2
0.3
Vk / √L
SHOAL CHANNEL
TOW:
BARGE: 195 x 35 FT.

ERRATA   11 August 1961

RESISTANCE OF BARGE TOWS, Model and Prototype Investigations, Civil Works Investigations 814 and 835 by U.S. Army Engineer Division, Ohio River, Corps of Engineers, Cincinnati, Ohio, August 1960.

1. Page 18, Formula (3), add brackets around all of equation following tanh.

2. Plate 64, change 9 ft. draft to 8.5 ft.

3. Plate 95, change H/D 0.40 to 0.406.

4. The following corrections in plotting should be made:

Plate	$V_k/\sqrt{L}$	Draft	1000 T-M/Hr	H/D	C
71	0.575	3.0	10.00		
	0.575	7.0	26.50		
	0.575	9.0	34.00		
	0.575	11.0	42.25		
74	0.45			0.60	2.16
	0.40			0.60	2.05
	0.35			0.60	2.03
82	0.45			0.657	2.36
	0.40			0.657	2.37
	0.45			0.60	2.27
	0.40			0.60	2.29
	0.45			0.50	2.08
	0.40			0.50	2.06
	0.35			0.50	1.98
	0.30			0.50	1.82
86	0.30			0.642	1.83
	0.25			0.642	1.80
	0.40			0.219	1.16